ICAR-CMFRI
Winter School on

RECENT ADVANCES IN FISHERY BIOLOGY TECHNIQUES FOR BIODIVERSITY EVALUATION AND CONSERVATION

01– 21 December 2018

Course Manual

Organised by

ICAR-Central Marine Fisheries Research Institute
Post Box No. 1603, Ernakulam North P.O., Kochi-682 018
Kerala, India

COURSE MANUAL

Lecture Series 3/2018

ICAR Sponsored

WINTER SCHOOL

on

Recent Advances in Fishery Biology Techniques for Biodiversity Evaluation and Conservation

ICAR-Central Marine Fisheries Research Institute

(Indian Council of Agricultural Research)

Post Box No. 1603, Ernakulam North P.O.

Kochi- 682 018, Kerala, INDIA

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Recent Advances in Fishery Biology Techniques for Biodiversity Evaluation and Conservation
CMFRI

Published by

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Kochi- 682 018, Kerala, India

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December, 2018

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FOREWORD

Fisheries is an important sector in India as it provides employment to millions of people and contributes to food security of the country. With a coastline of over 8,000 km, an Exclusive Economic Zone (EEZ) of over 2 million sq km, and with extensive freshwater resources, fisheries play a vital role. An estimated 4.0 million people depend for their livelihoods on the marine fisheries resources. Fish is a natural resource with capacity to rebuild. If not monitored and managed, over-exploitation will lead to stock depletion and some may become extinct. Harvest of this resource needs to be maintained at sustainable level through monitoring and control. For any conservation to take place effectively, an indepth study of the biology of the resource and its adaptive systems should be in place.

ICAR-Central Marine Fisheries Research Institute (CMFRI) has significantly contributed towards the development of marine capture fisheries and mariculture in the region, through 70 years of yeomen service to the nation. The wealth of information collected in fishery biology and biodiversity has contributed in strengthening its hold as the premiere fishery institute in the country. Its expertise in this area as well as several novel techniques are being used for effective management of the resource as well as in doubling the resource through Capture Based Aquaculture.

The Course Manual released on this occasion covers important aspects of fishery biology, ageing techniques, marine certification. Biodiversity evaluation, ecological analysis, economic evaluation, comanagement prepared by experts in their respective fields. I congratulate the Course Director, Dr. Rekha J Nair, Principal Scientist and her team Shri Ambareesh P.Gop, Scientist and Dr. V. Mahesh, Scientist, Course Co -Directors and other staff for their efforts in bringing out the Manual on time and to arrange the programme in a befitting manner.

A. Gopalakrishnan
Director, ICAR-Central Marine Fisheries Research Institute
Kochi, Kerala

December 2018

PREFACE

The application of scientific knowledge for the development of the fishing industry lies in an intimate knowledge of the biology of fishes. Without proper knowledge of the life, habits and behaviour of fishes, it would not be possible to plan, control and manage the fisheries resources in a satisfactory manner. The importance of knowledge of the natural history and ecology of organisms affecting the particular fishery cannot be overestimated. Such knowledge is largely the basis for fishery regulation. It also helps in determining the need to improve a given environment and in the required direction. Marine fisheries comprise of capture and management of fish and other commercially important organisms found in the seas. Effectively combining fisheries management and biodiversity conservation for both human and ecosystem well being is the central challenge of modern fishery governance. At the global level, the aims of fisheries management and of biodiversity conservation are, respectively, framed by the 1982 Law of the Sea Convention (LOSC) and the 1992 Convention on Biological Diversity (CBD) and related implementation instruments (such as the 1995 United Nations Fish Stocks Agreement, the 1995 Code of Conduct for Responsible Fisheries, and the 1995 Jakarta Mandate on Marine and Coastal Biological Diversity), each with its own sets of requirements. While this field is predominantly of the capture type, culture of certain marine organisms is also possible. In both cases, basic knowledge on the biology of fishes or other organisms of economic importance is necessary. Most conservation efforts are based on scientific management tools, which in turn rely on sound biological data and derivations from the same for farming the management recommendations. A wide array of techniques are used by fishery biologists to study fishes and these biological inputs used are further used to effectively manage the fisheries.

The present ICAR Sponsored Winter School on Recent Advances in Fishery Biology Techniques for Biodiversity Evaluation and Conservation is a step towards usage of recent techniques in fishery biology for effective fishery management and biodiversity conservation. The Course is designed to acquaint the participants with the different aspects of the fishery, trophodynamics, biology and fishery of pelagic, demersal, mollucan and crustacean fisheries and their interactions with the ecological variations. Classes on emerging areas of jellyfishes corals, marine mammals, sea birds and new areas of work which can be explored like stable isotope analysis, marine certification, ecolabelling has also been touched upon. The course module has been planned so that the participants have hands on experience in softwares like R, mapping of marine environmental variables, geostatistics as well as in molecular taxonomy. I hope this 21 day programme will strengthen the participants' knowledge and expertise in the area of fishery biology and productive use of information towards biodiversity conservation.

I wish to thank the HRD of Indian Council of Agricultural Research for giving us an opportunity to organize this Winter School. We are also grateful to Dr. A. Gopalakrishnan, Director, ICAR-CMFRI, for his support and guidance and providing all necessary facilities. We thank Dr. P.U Zacharia, Head, Demersal Fisheries Division for his support for the programme. The different faculty members we approached were very prompt in contributing their material and we thank each one of you for sparing your valuable time and effort helping us bring out this Manual on time. I wish to thank my Co-Directors Shri. Ambareesh P.Gop and Dr.V. Mahesh who have supported me throughout in organising the Winter School. The help and support provided by the technical, supporting and administrative staff is also acknowledged. I am sure the participants will find this Course Manual very valuable in their future research.

Rekha J Nair
Course Director

December 2018

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CHAPTER 01

Ichthyofaunal Diversity of India-challenges Ahead for a Mega Biodiversity Country

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Indian fish taxonomy has a long history, which started with Kautilya's *Arthasastra* describing fish as a source for consumption as early as 300 B.C and the epic on the second pillar of Emperor Ashoka describing the prohibition of consumption of fish during a certain lunar period, which can be interpreted as a conservation point of view. Modern scientific studies on Indian fishes could be traced to the initial works done by Linnaeus in 1758. M.E. Bloch is one of the pioneers in the field of fish taxonomy along with the naturalists, zoologists and botanists who laid the foundation for fisheries research in India such as Bloch and Schneider (1795-1801) and Lacepede (1798-1803). Russell worked on 200 fishes off Vizagapatanam during 1803. Hamilton (1822) described 71 estuarine fishes of India in his work *An Account of Fishes Found in the River Ganges and Its Branches.* The mid 1800s contributed much in the history of Indian fish taxonomy since the time of the expeditions was going through. Cuvier and Valenciennes work on taxonomy is indispensable to India and described 70 nominal species off Puducherry. Francis Day in the epoch-making book *"The Fishes of India: Being a Natural History of the Fishes Known to Inhabit the Seas and Fresh Waters of India, Burma, and Ceylon* and another book *Fauna of British India* Series in two volumes describing 1,418 species are the two most indispensable works on Indian fish taxonomy to date.

In the 20th century, the basis of intensive studies on the different families and groups of freshwater fishes was done by Chaudhuri along with Hora and his co-workers. Misra published *An Aid to Identification of the Commercial Fishes of India and Pakistan* and *The Fauna of India and Adjacent Countries (Pisces)* in 1976. Jones and Kumaran (1980) described about 600 species of fishes in the work *Fishes of Laccadive Archipelago* in 1980*.* Talwar and Kacker (1984) gave a detailed description of 548 species under 89 families in his work Commercial *Sea Fishes of India*. FAO *Species Identification Sheets for Fishery Purposes- Eastern Indian Ocean* (*Fisher* and Whitehead, 1974) and FAO *Species Identification Sheets for Fishery Purposes- Western Indian Ocean* (Fischer and Bianchi, 1984) are still a valuable guide for researchers. Talwar and Jhingran (1991a, 1991b) published description on 930 inland fish species of India known till date. Gopi and Misra (2014) reported 2443 species belonging to 230 families distributed along the Indian region. Reported that Gobiidae (190 spp), Pomacentridae (92), Labridae (85), Serranidae (85), Carangidae (66), Blennidae (65), Apogonidae (63), Chaetodontidae (48), Lutjanidae (45) were the high species rich families occurring along the Indian coast.

Species identification of finfish

Fisheries resources are one of the most important renewable resources. With increasing fishing pressure, the only option left for the sustainability of fisheries resources is their rational management. Scientific management is possible with a thorough knowledge of the dynamics of the fish stocks. For a meaningful study of the dynamics, knowledge of the natural history of the species is necessary and this in turn can be acquired by the correct identification of fish species. Taxonomy of fishes assumes greater significance in tropical seas where an assembly of closely interrelated and morphologically analogous species occurs. The role of taxonomy and proper identification cannot be overstressed in studies of population dynamics. Acquaintance with the main species should be such that there should be no errors in identification of them in any special form such as racial differentiation, abnormalities, malformation due to decay or disease. As to species of less importance, collections and observations can be made for taxonomic studies which will be useful in future. Species identification study is also a step towards understanding the bewildering biodiversity that characterizes the marine ecosystem. Measuring linear dimensions of whole or parts of fish is probably the most widely used technique in taxonomic studies. Such observations are made with taps and calipers. Measurements are usually but not always taken along straight lines.

Species diversity

Taxonomists also play an important role in supporting the study of the richness of species diversity as well as protecting and making vigilant of the diverse system. The finfish species diversity in Indian region is rich and gives immense opportunity to the taxonomic research (Table 1). The assessed fish diversity of India is not comprehensive and the undescribed species revealed that they are yet to be explored making the country more biodiversity rich. Hence the need to explore the ichthyofaunal diversity of India to be looked into as they pose major threats that need to be tackled and sorted out. The role of Marine protected areas (MPAs) and fish sanctuaries have been designated in many parts of India, which can help to protect and restore threatened species. Human activities are the major causes for the loss of biodiversity and degradation of marine and coastal habitats, which needs immediate attention and comprehensive action plan to conserve the biodiversity for living harmoniously with nature. Some of the measures such as control of excess fleet size, control of some of the destructive gears, regulation of mesh size, avoiding habitat degradation of nursery areas of the some of the species, reduce the discards of the low value fish, protection of spawners, implementation of reference points and notification of marine reserves for protection and conservation of marine and coastal biodiversity. The Wild Life (Protection) Act, 1972 amended by the Government make sure of the species protected under this Act and any capture, killing and trade of these species is punishable.

Table 1**. Finfish species diversity in selected families of fishes of India**

Family	Common Name	No. of Species
Stromateidae	Pomfrets	2
Sphyrnidae	Hammer- head Shark	5
Sphyraenidae	Barracudas	7
Rajidae	Rays	8
Trichiuridae	Ribbon fish	8
Rhinobatidae	Guitar fish	10

Polynemidae	Threadfins	11
Mugilidae	Mullets	18
Scombridae	Mackerel, Tunas &Bonitos	22
Leiognathidae	Pony fishes	24
Holocentridae	Rabbit fishes	25
Carcharhinidae	Grey Shark	26
Clupeidae	Sardine	26
Mullidae	Goat fishes	27
Dasyatidae	Sting rays	28
Ophidiidae	Cusk eels	28
Haemulidae	Grunts	28
Nemipteridae	Threadfin breams	33
Engraulidae	Anchovy	34
Myctophidae	Lantern fish	41
Syngnathidae	Seahorses & Pipe fishes	42
Sciaenidae	Croakers	43
Lutjanidae	Snapper	45
Carangidae	Trevallies & Jacks	66
Serranidae	Groupers	85
Pomacentridae	Damsel & Clown fishes	92

Diversify of Marine Fishes of India

Of the 33,059 total fish species of the world, India contributes of about 2492 marine fishes owing to 7.4% of the total marine fish resources. Of the total fish diversity known from India, the marine fishes constitute 76 percent, comprising of 2492 species belonging to 941 orders, 240 families (Table 2). Andaman and Nicobar archipelago shows the highest number (1431) among the fish diversity-rich areas in the marine waters of India, followed by the east coast of India with 1121 species and the west coast with 1071. Around 91 species of endemic marine fishes are recognized to occur in the coastal waters of India. A total of 50 marine fishes identified from India fall into the Threatened category as per the IUCN Red List, and about 45 species are Near-Threatened and already on the path to vulnerability. Though, merely certain species (10 elasmobranchs, 10 seahorses and one grouper) are listed in Schedule I of the Wildlife (Protection) Act, 1972 of the Government of India for the protection of the species.

Table 2. **Species diversify of marine Fishes of India**

No	Order	Family	No. of Genera	No. of species
	Class: Elasmobranchii			
1	Hexanchiformes			
	1	Hexanchidae	2	2
2	Heterodontiformes			
	2	Heterodontidae	1	1
3	Echinorhiniformes			
	3	Echinorhinidae	1	1
4	Orectolobiformes			
	4	Rhincodontidae	1	1
	5	Hemiscylliidae	1	5
	6	Stegostomatidae	1	1
	7	Ginglymostomatidae	1	1
5	Lamniformes			
	8	Odontaspididae	2	3
	9	Pseudocarchariidae	1	2
	10	Lamnidae	2	3
	11	Alopiidae	1	3
6	Carcharhiniformes			
	12	Pseudotriakidae	1	1
	13	Scyliorhinidae	6	9
	14	Proscylliidae	1	1
	15	Triakidae	2	4
	16	Hemigaleidae	4	4
	17	Carcharhinidae	10	26
	18	Sphyrnidae	2	5
7	Squaliformes			
	19	Etmopteridae	2	7
	20	Somniosidae	2	2
	21	Centrophoridae	2	8
	22	Squalidae	1	5
8	Pristiformes			
	23	Pristidae	2	5
9	Torpediniformes			
	24	Narkidae	2	4
	25	Narcinidae	2	7
	26	Torpedinidae	1	5
10	Rajiformes			
	27	Rhinobatidae	4	10
	28	Rhyncobatidae	1	4
	29	Zonobatidae	1	1
	30	Acanthobatidae	1	1
	31	Rajidae	7	8

11	Myliobatiformes			
	32	Hexatrygonidae	1	1
	33	Dasyatidae	7	28
	34	Gymnuridae	2	4
	35	Myliobatidae	2	8
	36	Mobulidae	2	9
	37	Placiobatidae	1	1
	Sub class: Holocephali			
12	Chimaeriformes			
	38	Rhinochimaeridae	1	1
	39	Chimaeridae	1	1
	Class Actinopterygii			
13	Elopiformes			
	40	Elopidae	1	2
	41	Megalopidae	1	1
14	Albuliformes			
	42	Albulidae	1	2
15	Notacanthiformes			
	43	Halosauridae	2	5
	44	Notacanthidae	1	1
16	Anguilliformes			
	45	Anguillidae	1	5
	46	Moringuidae	1	6
	47	Muraenidae	10	38
	48	Synaphobranchidae	2	3
	49	Ophichthidae	17	24
	50	Colocongridae	1	1
	51	Congridae	12	17
	52	Muraenesocidae	4	6
	53	Nemichthyidae	2	2
	54	Serrivomeridae	1	1
	55	Nettastomatidae	2	2
17	Clupeiformes			
	56	Clupeidae	12	26
	57	Dussumieriidae	1	2
	58	Engraulidae	5	34
	59	Chirocentridae	1	2
	60	Pristigasteridae	4	12
18	Gonorynchiformes			
	61	Chanidae	1	1
19	Siluriformes			
	62	Ariidae	10	25
	63	Plotosidae	1	3
	64	Bagaridae	2	4
20	Stomiiformes			
	65	Gonostomatidae	4	6

	66	Sternoptychidae	4	8
	67	Phosichthyidae	2	3
	68	Stomiidae	6	9
21	Aulopiformes			
	69	Chlorophthalmidae	1	3
	70	Ipnopidae	2	4
	71	Synodontidae	4	23
	72	Paralepididae	2	3
	73	Evermannellidae	2	2
	74	Alepisauridae	1	2
22	Myctophiformes			
	75	Neoscopelidae	2	3
	76	Myctophidae	11	41
23	Lampriformes			
	77	Veliferidae	1	1
	78	Lophotidae	1	1
	79	Regalecidae	1	1
	80	Ateleopodidae	2	3
24	Polymixiiformes			
	81	Polymixiidae	1	4
25	Gadiformes			
	82	Bregmacerotidae	1	1
	83	Macrouridae	9	18
	84	Moridae	1	2
26	Ophidiiformes			
	85	Ophidiidae	16	28
	86	Carapidae	3	5
	87	Bythitidae	6	7
	88	Aphyonidae	1	1
27	Batrachoidiformes			
	89	Batrachoididae	4	6
28	Lophiiformes			
	90	Lophiidae	2	4
	91	Antennariidae	2	9
	92	Chaunacidae	1	1
	93	Ogcocephalidae	5	11
	94	Diceratiidae	1	1
	95	Oneirodidae	1	1
	96	Ceratiidae	1	1
29	Mugiliformes			
	97	Mugilidae	7	18
30	Atheriniformes			
	98	Atherinidae	4	9
	99	Notocheiridae	1	1
31	Beloniformes			
	100	Belonidae	4	8

	101	Hemiramphidae	5	16
	102	Zenarchopteridae	2	8
	103	Exocoetidae	6	18
32	Stephanoberyciformes			
	104	Melamphaidae	1	1
33	Cypridontiformes			
	105	Aplocheilidae	1	1
34	Beryciformes			
	106	Monocentridae	1	1
	107	Trachichthyidae	2	3
	108	Berycidae	2	4
	109	Holocentridae	4	25
35	Argentiniformes			
	110	Platytroctidae	3	4
	111	Alepocephalidae	9	14
36	Zeiformes			
	112	Parazenidae	1	1
	113	Grammicolepididae	2	2
	114	Zeidae	1	2
37	Gasterosteiformes			
	115	Pegasidae	2	4
38	Syngnathiformes			
	116	Aulostomidae	1	1
	117	Fistulariidae	1	3
	118	Centriscidae	2	4
	119	Macrorhamphosidae	1	1
	120	Solenostomidae	1	2
	121	Syngnathidae	14	42
39	Scorpaeniformes			
	122	Apistidae	1	1
	123	Aploactinidae	4	6
	124	Bembridae	1	1
	125	Dactylopteridae	1	5
	126	Peristediidae	5	7
	127	Platycephalidae	11	16
	128	Scorpaenidae	15	35
	129	Setarchidae	2	3
	130	Synanceiidae	5	13
	131	Tetrarogidae	9	12
	132	Triglidae	2	7
40	Polynemiformes			
	133	Polynemidae	5	11
41	Perciformes			
	134	Acropomatidae	2	5
	135	Ambassidae	2	11
	136	Apogonidae	19	63

137	Bathyclupeidae	1	1
138	Bramidae	3	3
139	Caesionidae	4	16
140	Caproidae	1	2
141	Carangidae	20	66
142	Centrogenyidae	1	1
143	Chaetodontidae	8	48
144	Coryphaenidae	1	2
145	Datnioididae	1	1
146	Drepaneidae	1	2
147	Echeneidae	3	6
148	Emmelichthyidae	1	1
149	Gerreidae	2	11
150	Haemulidae	3	28
151	Hapalogenyidae	1	1
152	Kyphosidae	1	3
153	Lactariidae	1	1
154	Latidae	2	2
155	Leiognathidae	9	22
156	Lethrinidae	5	24
157	Lobotidae	1	1
158	Lutjanidae	10	45
159	Malacanthidae	2	3
160	Menidae	1	1
161	Monodactylidae	1	3
162	Mullidae	3	27
163	Nemipteridae	4	33
164	Opistognathidae	1	7
165	Ostracoberycidae	1	1
166	Pempheridae	2	7
167	Plesiopidae	3	5
168	Pomatomidae	1	1
169	Priacanthidae	3	9
170	Pseudochromidae	4	9
171	Rachycentridae	1	1
172	Sciaenidae	19	43
173	Serranidae	19	85
174	Sillaginidae	2	11
175	Sparidae	7	12
176	Symphysanodontidae	1	3
177	Toxotidae	1	2
178	Acanthuridae	5	39
179	Ammodytidae	1	3
180	Blenniidae	26	65
181	Callionymidae	4	21
182	Cepolidae	2	4
183	Champsodontidae	1	2
184	Chiasmodontidae	3	3

	185	Cirrhitidae	4	8
	186	Clinidae	1	1
	187	Creediidae	1	1
	188	Eleotridae	11	18
	189	Ephippidae	3	4
	190	Gobiidae	71	190
	191	Kuhliidae	1	3
	192	Kurtidae	1	1
	193	Labridae	28	85
	194	Cichlidae	2	3
	195	Samaridae	2	2
	196	Microdesmidae	3	9
	197	Pentacerotidae	1	1
	198	Percophidae	2	3
	199	Pholidichthyidae	1	1
	200	Pinguipedidae	1	12
	201	Pomacanthidae	6	21
	202	Pomacentridae	19	92
	203	Scaridae	7	29
	204	Scatophagidae	1	1
	205	Schindleriidae	1	2
	206	Siganidae	1	17
	207	Terapontidae	2	4
	208	Trichonotidae	1	2
	209	Tripterygiidae	3	8
	210	Uranoscopidae	2	6
	211	Xenisthmidae	1	1
	212	Zanclidae	1	1
	213	Ariommatidae	1	1
	214	Centrolophidae	1	2
	215	Istiophoridae	3	5
	216	Nomeidae	2	3
	217	Scombridae	11	22
	218	Scombrolabracidae	1	1
	219	Stromateidae	1	2
	220	Trichiuridae	6	12
	221	Kraemeriidae	1	1
	222	Sphyraenidae	1	10
	223	Gempylidae	9	10
	224	Xiphiidae	1	1
42	Pleuronectiformes			
	225	Psettodidae	1	1
	226	Citharidae	1	1
	227	Paralichthyidae	2	9
	228	Bothidae	9	21
	229	Pleuronectidae	3	4
	230	Soleidae	11	27
	231	Cynoglossidae	3	21

43	Tetradotnifromes			
	232	Triacanthodidae	6	6
	233	Triacanthidae	3	5
	234	Balistidae	11	22
	235	Monacanthidae	14	22
	236	Ostraciidae	4	7
	237	Triodontidae	1	1
	238	Tetradontidae	8	32
	239	Diodontidae	3	6
	240	Molidae	3	4
			941	2492

Reference: Table prepared based on the list of species published in Eschmeyer, W. N., 1998; Fricke et al., 2018; Gopi, K. C. and Mishra, S. S., 2015, Joshi et al., 2017.

Ecosystem Services from Marine Ecosystems

Marine ecosystem services include: Provisional services, regulating services, supporting services and cultural services.

Provisional services are the goods obtained from marine and coastal ecosystems such as finfish, molluscs, seaweeds, shell, firewood, wood, medicine, genetic material and ornamental resources. Food provisioning in the form of fisheries catch is one of the vital services resulting from all coastal and marine ecosystems. Bioprocessing from the seas produces many foodstuffs such as antibiotics, antifreeze and antifouling compounds. Coral reefs provide several natural bioactive compounds, which are not available in the terrestrial environment. Mangrove forests are good reservoirs of chemical compounds, wood products and medicinal plants. The shark fin, air bladder from croakers, gill filaments from rays, pearls from oysters, shells of molluscs is essential supplies from marine fauna.

Regulating services are the welfares, human get from the regulation of ecosystem processes. This comprises climate regulation, sea erosion control, waste removal, water sanitization, air quality maintenance. Mangroves, seagrass, rocky, sandy, mudflats and estuaries play a significant role in shoreline protection, sea level rise, and protection from floods and soil erosion, processing of domestic waste and safeguarding land from storms. Mangroves have an inherent capacity to absorb heavy metals and other domestic effluents making the sea water clean. The coral reefs protect land from waves and storms and prevent sea shore erosion. Estuaries, brackish water and marshes play a dynamic part in preserving water cycle and filtering water from domestic wastes. Marine ecosystem plays vital role in climate regulation by way of adjusting carbon dioxide exchange between atmosphere and ocean. The photosynthesis of marine plants absorbs carbon dioxide and release oxygen.

Supporting services include a provision of different habitats, primary productivity, and nutrient cycling and soil formation. The majority of the marine species migrates to coastal zones like estuaries, mangroves and seagrass beds for breeding and larval development. Estuaries play a significant part as nursery zones for fisheries because it links between coastal, marine, and freshwater ecosystem.

Cultural services comprise tourism, recreation, aesthetic and spiritual services, traditional information and education and research services. The most significant cultural services provided by the coastal and marine ecosystem are tourism and recreation. The natural services are greatly prized by people and contribute to human well-being, thus providing important economic cost. The extensive stretches of beaches, rocky habitats, coral reefs, estuaries and brackish water waterways are the attractive scenic opportunities. Boating, walking, fishing, swimming, beach riding, scuba diving, religious ceremonials are certain activities that people relishing globally and are important economic activity.

Most important provisional service provided by the Marine Fisheries sector are the production food fishes. The estimated marine fish landings for India was 3.83 million tonnes in 2017 which was slightly higher than (5.5%) as compared to 2016. For the purpose of easy comparison fish production, the coastal area is divided into four regions ie North West coast (Gujarat, Maharashtra, Daman Diu), South West coast (Karnataka, Kerala, Goa), South East coast (Tamilnadu, Andhra Pradhesh, Pondicherry) and North East coast (Odisha, West Bengal). The production of fish from South West and North West coast was around 12.33 lakh tonnes and 12.32 tonnes respectively. The South East coast and North East coast contributed 8.82 lakh tonnes and 4.88 lakh tonnes respectively. The maritime states like Gujarat, Tamilnadu, Kerala and Karnataka contributed more than 5 lakh tonnes of fish to all India catch during 2017.

North West coast

The North West Coast consists of Gujarat, Maharashtra, and Daman & Diu which is the most productive area along the north west coast. Gujarat has the longest coastline of more than 1,600 km and the most extensive continental shelf of nearly 164,000 km^2, which represents nearly 20% and 32 % of India's coastline and continental shelf. The EEZ of Gujarat covers 214,000 km. The coast has broadly been divided into four sections: the Gulf of Kachchh, the Saurashtra coast, the Gulf of Khambhat and the South Gujarat coast. The ecological importance is that India's first Marine National Park was notified in the Gulf of Kachchh. In the ecological sense, the habitats exhibit considerable diversity and they include mangroves, salt marshes, coral reefs, beaches, dunes, estuaries, intertidal mudflats, gulfs, bays and wetlands. Gujarat has India's second largest extent of the area under the mangroves. The major rivers are Narmada, Tapti, Sabarmati, and Mahi. Gulf of Khambhat (Gulf of Cambay) is 190 km wide at its mouth between Diu and Daman, rapidly narrows to 24 km. The Gulf of Kachchh is rather shallow with a depth of nearly 60 m at the mouth to less than 20 m near the head. The total gulf area is about 7350 km^2. In the Gulf of Kachchh, there are 42 islands & some islets, covering a total area of about 410.6 km^2. About 306 fish species are listed from the sea and coastal waters of Gujarat. The Bombay duck (*Harpodon nehereus*) fishery is dominant at Nawabunder, Rajpara and Jaffrabad along the Saurashtra coast. Out of total 306 reported species, 23 fish species were found in the IUCN's Red Data list. Importantly, 10 of these species belong to Elasmobranch families, including the Whale shark, are also listed in Schedule I of Wildlife Protection Act, 1972. The Maharashtra coast that stretches between Bordi/Dahanu in the North and Redi/Terekhol in the South is about 720 km long and 30-50 km wide. The shoreline is indented by several west flowing river mouths, creeks, bays, headlands, promontories and cliffs. There are about 18 noticeable creeks/

estuaries along the coast, many of which harbor mangrove habitats. The Gulf of Cambay and North Bombay coast are also rich in Bombay duck fisheries. About 285 species have been reported from the coast.

Fish species diversity reported from North West coast are given below:

Whitefish: *Lactarius lactarius*

Sardine: *Sardinella longiceps*

Dolphinfish: *Coryphaena hippurus*

Golden anchovy*:* *Coilia dussumieri*

Indian mackerel*:* *Rastrelliger kanagurta*

Bombayduck: *Harpodon nehereus*

Wolfherring*:* *Chirocentrus nudus, Chirocentrus dorab*

Lizardfish*:* *Saurida tumbil, Saurida undosquamis*

Pomfrets: *Pampus argenteus, Parastromateus niger*

Seerfishes*:* *Scomberomorus commerson , Scomberomorus guttatus*

Fullbeaks: *Ablennes hians, Strongylura strongylura, Tylosurus sp.*

Ribbonfish: *Trichiurus lepturus, Lepturacanthus savala, Eupleurogramus muticus*

Tuna*:* *Euthynnus affinis ,Thunnus tonggol, Auxis thazard , Katsuwonus pelamis*

Polynemids: *Polydactylus mullani, Polynemus indicus, Eleutheronema tetradactylum*

Threadfin breams*:* *Nemipterus japonicus, Nemipterus randalli, Nemipterus bipunctatus*

Barracuda*:* *Sphyraena putnamae, Sphyraena jello, Sphyraena obtusata* and *Sphyraena barracuda.*

Croakers*:* *Johnius borneensis, Johnius macrorhynus, Otolithes cuvieri, Otolithes biauritus, Pennahia anea, Johnius belangeri, Protonibea diacanthus*

Catfishes: *Osteogeneiosus militaris, Plicofolis dussumeiri, Nemapteryx caelata, Plicofolis tenuispinis*

Elasmobranchs: *Scoliodon laticaudus, Himantura uarnacoides, Carcharhinus sorrah, Rhizoprionodon acutus, Rhizoprionodon oligolinx*

Groupers*:* *Epinephelus diacanthus, Epinephelus tauvina, Epinephelus latifasciatus, Epinephelus areolatus*

South West coast

The South West coast stretches like a beautiful chain formed from the coastal districts of the states of Goa, Karnataka and Kerala. Many river mouths, creeks, small bays, cliffs and beaches, interspersed with historic forts, lend an alluring charm to this landscape. Konkan is also rich in coastal and marine biodiversity. Mangrove forests, coral reefs, charismatic marine species like dolphins, porpoises, whales, sea turtles, etc., many species of coastal birds and other fauna make the Konkan coast a veritable treasure trove of biological diversity. The Malvan Marine Sanctuary has a spread over of 29 km^2; the sanctuary is rich in coral and marine life. The Karwar group of islands with its unique rocky with sandy shore supports a wide range of fauna. There are more than 170 different species of food fishes landing in the coast and is famous for its large shoals of Mackerel, *Rastrelliger kanagurta* dominating the coasts of Karnataka. Malabar Coast which stretches from Goa to Kanyakumari supports vast habitats such as Mangroves, Swamps, coral reefs, Sea grass meadows, beaches and deltaic regions. About 308 fish species have been reported off Malabar Coast, of which most of them are clupeids followed by, groupers, anchovies, scombrids, snappers and butterfly fishes.

The Union territory of Lakshadweep consists of 36 islands covering an area of 32 km^2 of which 10 islands are inhabited, 20,000 km^2 of lagoons and 4000 km^2 oceanic zones. Among the fishes of Lakshadweep, those of ornamental value are abundant. Of the 603 species of marine fishes that are reported from the islands at least 300 species belong to the ornamental fish group. Oceanic species of tuna such as Skipjack and Yellowfin tuna constitute the major tuna resources from Lakshadweep Islands. The main economy of the islanders is dependent on the tuna catch and fishing is done for nearly six months of the year from October to April. The most common species of sharks that occur in Lakshadweep are the Spade-nose shark/Yellow dog shark, and the Milk shark. The Blacktip Shark and Hammerhead shark are also commonly found in the waters around Lakshadweep.

Fish species diversity reported from South West coast were given below:

Whitefish:	*Lactarius lactarius*
Mackerel:	*Rastrelliger kanagurta*
Catfish:	*Netuma thalassina*
Priacanthids:	*Priacanthus hamrur, Cookeolus japonicus*
Threadfin breams*:*	*Nemipterus japonicus, Nemipterus randalli*
Eels:	*Muraenesox bagio, Muraenesox cinerius*
Pomfrets:	*Pampus argenteus, Pampus chinensis*
Sardines:	*Sardinella longiceps, Sardinella fimbriata, Sardinella gibbosa, Sardinella albella*
Whitebaits*:*	*Stolephorus devisi, Stolephorus commersonii, Stolephorus waitei, Stolephorus insularis, Stolephorus indicus*
Flatfishes:	*Cynoglossus macrostomus, Cynoglossus macrolepidotus, Cynoglossus bilineatus*
Ribbonfishes: *T*	*richiurus lepturus, Trichiurus auriga, Lepturacanthus savala,*

	Eupleurogramus muticus
Seerfishes:	*Scomberomorus commerson, Scomberomorus guttatus, Acanthocybium solandri*
Tunas:	*Thunnus albacares, Katsuwonus pelamis, Euthynnus affinis, Auxis thazard, Auxis rocheii, Thunnus tonggol, Sarda orientalis, Gymnosarda unicolor*
Groupers: *E*	*pinephelus diacanthus, Epinephelus flavocaeruleus, Epinephelus longispinis, Epinephelus areolatus, Variola louti, Cephalopholis miniata*
Snappers:	*Lutjanus bohar, Pristipomoides typus, Lutjanus gibbus, Pristipomoides multidens, Pristipomoides filamentosus, Aphareus rutilans, Aphareus virescens, Lutjanus kasmira, Lutjanus lutjanus, Lutjanus bengalensis, Lutjanus rivulatus.*
Croakers:	*Johneops sina, Otolithes ruber, Otolithes cuvieri, Johnius belangeri, Johnius anaeus, Nibea soldado, Johnius glaucus, Johnius macropterus*
Lizardfishes:	*Saurida tumbil, Saurida undosquamis, Trachinocephalus myops, Synodus englemani, Synodus gracilis*
Pigface breams:	*Lethrinus mahsena, Lethrinus cochyliatus, Lethrinus elongatus*
Skate:	*Rhina ancylostoma, Rhinobatos obtusus, Rhinobatos annandalei*
Carangids*:*	*Decapterus russellii, Selaroides leptolepis, Caranx ignobilis, Selar crumenophthalmus, Alectis indicus, Alectis ciliaris, Megalaspis cordyla, Scomberoides commersonianus, Elegatis bipinnulata*
Ray:	*Dasyatis microps, Himantura bleekeri, Himantura imbricata, Himantura fai, Himantura uarnak, Himantura jenkinsii, Himantura gerrardi, Mobula japonica, Mobula tarapacana, Taeniura meyeni, Pteroplatytrygon violacea, Rhinoptera javanica, Neotrygon kuhlii*
Sharks:	*Carcharhinus limbatus, Carcharhinus falciformis, Carcharhinus longimanus, Scoliodon laticaudus, Sphyrna lewini, Isurus oxyrinchus, Galeocerdo cuvieri, Alopias pelagicus, Alopias superciliosus, Carcharhinus leucas, Carcharhinus brevipinna, Carcharhinus amblyrhynchoides, , Carcharhinus albimarginatus, Carcharhinus sorrah, Prioncace glauca, Stegostoma fasciatum, Echinorhinus brucus, Nebrius ferrugineus, Triaenodon obesus, Loxodon macrorhinus*

South East coast

The Gulf of Mannar located in the Southern part of the Bay of Bengal with a string of 21 islands which has been declared as a marine National park under the Wild Life (Protection) Act 1972 by the Government of India. The reserve covers 10,500 km^2, which comprises of a variety of sensitive marine habitats like coral reefs, mangroves and sea grasses, and could be considered as one of the most productive ecosystems. The core area of the reserve is comprised of a 560km^2 of coral islands and shallow marine habitat. The Gulf of Mannar and adjacent areas alone produces about 20% of the marine fish catch in Tamil Nadu. Of the 2492 fish species distributed in Indian waters, 1182 species have so far been recorded from the Gulf of Mannar. The finfish resources, mainly comprises of small pelagics, barracudas, silver bellies, rays, skates, eels, carangids, flying fish, full beaks and half beaks. The demersal finfish resources, mainly associated coral reefs are threadfin breams, grouper, snappers, emperor and reef associated fishes. Further, large pelagic species like skipjack tuna, yellow fin tuna, bigeye tuna, kawakawa, frigate tuna and seer fish, bill fishes, eagle rays are most abundant in offshore and oceanic areas, but also occur in coastal waters are found in certain areas of the Gulf of Mannar.

Palk Bay is situated on the southeast coast of India encompassing the sea between Point Calimere near Vedaranyam in the north and the northern shores of Mandapam to Dhanushkodi in the south. The Palk Bay itself is about 110 km long and is surrounded on the northern and western sides by the coastline of the State of Tamil Nadu in the mainland of India. The coastline of Palk Bay has coral reefs, mangroves, lagoons, and sea grass ecosystems. Elasmobranchs are the largest group of fishes and are well represented in the fishery wealth of the Rameswaram Island on the Palk Bay side.

Fish species diversity reported from South East coast are given below:

Dolphinfish: *Coryphaena hippurus*

Cobia: *Rachycentron canadum*

Indian halibut: *Psettodes erumei*

Mackerel: *Rastrelliger kanagurta, Rastrelliger faughni*

Lizardfishes: *Saurida tumbil, Saurida undosquamis, Trachinocephalus myops*

Pomfrets: *Pampus argenteus, Pampus chinensis*

Flying fish: *Hirundichthys coromandelensis, Cheliopogon spilopterus, Cheliopogon spilopterus bahiensis*

Needlefishes: *Strongylura strongylura, Strongylura leiura, Tylosurus crocodilus, Ablennes hians*

Sardines: *Sardinella gibbosa, Sardinella longiceps, Sardinella albella, Sardinella fimbriata, Amblygaster clupeoides, Amblygaster sirm*

Tunas: *Thunnus albacares, Katsuwonus pelamis, Euthynnus affinis, Auxis thazard, Auxis rocheii, Thunnus tonggol, Sarda orientalis, Gymnosarda unicolor*

Seerfish: *Scomberomorus commerson, Scomberomorus guttatus, Scomberomorus lineolatus, Acanthocybium solandri*

Billfishes: *Istiophorus indica, Istiophorus platypterus*, *Xiphias gladius*, *Tetrapterus audax*

Pigface breams:	*Lethrinus lentjan, Lethrinus nebulosus, Lethrinus miniatus, Lethrinus ramak, Lethrinus ornatus*
Threadfin breams:	*Nemipterus japonicus, Nemipterus randalli, Nemipterus bipunctatus, Nemipterus peronii, Scolopsis bimaculata, Scolopsis vosmeri*
Snappers:	*Lutjanus lutjanus, Lutjanus fulvus, Pristipomoides filamentosus, Lutjanus ehrenbergii, Lutjanus indicus, Lutjanus fulviflamma, Lutjanus madras, Lutjanus quinquelineatus*
Goatfish:	*Upeneus supravittatus, U.moluccensis, U.bensasi, U.sundaicus, U.sulphureus, U.tragula, U.taeniopterus, U.vittatus, Parupeneus indicus, Parupeneus heptacanthus.*
Silverbellies:	*Eubleekeria jonesi, Karalla dussumieri, Karalla daura, Leiognathus brevirostris, Leiognathus lineolatus, Leiognathus equulus, Gazza minuta,, Secutor ruconius, Deveximentum insidiator, Photopectoralis bindus, Eubleekeria splendens*
Croakers:	*Otolithes ruber, Kathala axillaris, Nibea maculata, Johnius carutta, J.dussumieri, Pennahia anea, Protonibea diacanthus, Johnieops dussumieri, Dendrophysa russelli, Nibea soldado, Panna microdon*
Carangids:	*Decapterus russellii, Selaroides leptolepis, Caranx ignobilis, Selar crumenophthalmus, Alectis indicus, Alectis ciliaris, Megalaspis cordyla, Scomberoides commersonianus, Elegatis bipinnulata, Parastromateus niger*
Groupers:	*Epinephelus malabaricus, Epinephelus undulosus, Epinephelus bleekeri, Epinephelus merra, Epinephelus coioides, Epinephelus fasciatus, Epinephelus aerolatus, Epinephelus latifasciatus, Epinephelus radiatus, Epinephelus longispinis, Cephalopholis sonnerati*
Catfishes:	*Netuma thalassina, Plicofollis tenuispinis, Plicofollis dussumieri, Arius arius, Arius maculata, Plotosus lineatus, Plotosus canius, Plotosus limbatus*
Sharks:	*Sphyrna lewini, Chiloscyllium griseum, Chiloscyllium falciformis, Carcharhinus brevipinna, Carcharhinus limbatus*
Rays:	*Mobula japonica, Mobula tarapacana, Manta birostris, Gymnura poecilura, Himantura gerrardi, Himantura imbricata, Himantura uarnak, Himantura fai, Rhinoptera javanica, Dasyatis zugei, Himantura marginata, Himantura jenkinsii, Dasyatis centroura, Taeniura meyeni, Neotrygon kuhlii, Pteroplatytrygon violacea, Pastinachus sephen, Pastinachus gracilicaudus, Gymnura poecilura, Aetobatus narinari, Aetomylaeus vespertilio, Aetobatus flagellum, Rhinoptera javanica*

Andaman and Nicobar islands

The Andaman and Nicobar islands situated in the Bay of Bengal constitutes of about 524 islands with a coastline of 1962 km. The major habitats of the coastal region include the bio diverse coral reefs with both fringing reefs off the east coast and barrier reefs off the west coast, mangroves, estuaries and wetlands. Fish communities reach their highest degree of diversity in these ecosystems, and differ enormously within and between reefs in the same area and between geographic regions since the confluence of Andaman fishes with the waters of pacific as well as Indian Ocean. A total of 1431 species under 586 genera with 175 families has been reported from Andaman waters. The number of reef fishes is the highest among the Indian reefs with a contribution of 72.5% of the recorded fishes of the region. Major species belong to the family Pomacentridae and Gobiidae.

North East coast

The North East coast consists of West Bengal and Orissa states along the North East coast of India. The Sundarbans biosphere reserve is a majestic natural region in the world which covers 102 swampy island, mangroves, estuaries, backwaters and waterways. The Sundarbans represent the largest remaining tract of coastal mangrove wetlands in tropical Asia formed at the estuarine phase of the Ganges-Brahmaputra river system. The Indian Sundarbans of India occupies 9630 Km^2 and are bounded by River Hooghly in the West, River Raimangal in the East, Bay of Bengal in the South and Dampier Hodges line in the North. There are 56 islands of various dimensions and shapes in Sundarbans and these are separated from each other by a network of tidal channels. Sundarban boast around 172 species of fishes. Along the coast the fisheries comprise of sardines, sharks anchovies and other miscellaneous clupeoids. Sundarbans is the nursery for nearly 90% of the aquatic species of the eastern coast, the coastal fishery of eastern India is dependent upon Sundarban. Orissa has a total brackish water reserve of 417,537 ha, estuaries, lakes and backwater account for 247,850 ha, 79,000 ha and 8,100 ha respectively. The Mahanadi estuary lies in the Cuttack and Puri districts of Orissa and drains into Bay of Bengal.

Fish species diversity reported from North East coast were given below:

Sea bass:	*Lates calcarifer*
Hilsa:	*Tenualosa ilisha*
Mullets:	*Liza parsia, Liza tade*
Pomfret:	*Pampus argenteus*
Milkfish:	*Chanos chanos*
Sardine:	*Sardinella longiceps*
Ribbonfishes:	*Trichiurus lepturus*
Mackerel:	*Rastrelliger kanagurta*
Lizardfish:	*Saurida undosquamis*

Flatfish*:*	*Cynoglossus arel*
Croakers*:*	*Otolithes ruber*
Goatfishes:	*Upeneus vittatus*
Golden anchovy*:*	*Coilia dussumieri*
Bombay duck*:*	*Harpadon nehereus*
Barracuda*:*	*Sphyraena jello, Sphyraena barracuda*
Threadfin breams*:*	*Nemipterus japonicus, Nemipterus randalli*
Tuna:	*Thunnus albacores, Katsuwonus pelamis, Auxis thazard*
Polynemids*:*	*Polydactylus indicus, Eleutheronema tetradactylum, Leptomelanosoma indicum, Polynemus paradiseus*

Challenges ahead for Ichthyofaunal mega diversity

The major challenges to Ichthyofaunal diversity are:

- **According to FAO**, the biodiversity research had been prioritized and several new fish identification tools have been developed. But the actual transfer and adoption of these fish identification tools in marine biodiversity management and conservation is minimal.
- **FAO urges** to take initiatives to strengthen the fish identification and biodiversity research among Scientists, stakeholders and the users. The strengthening of taxonomic research creates jobs for taxonomists, research funding and infrastructure facilities to conduct research on taxonomy leading to the revision and the stable nomenclature of different groups of fishes.
- **FAO requests** to develop more local reference collections of fish specimens in all the states for the purpose of reference museums, encourage, collaboration of fish taxonomy research.
- **Creation** of awareness programme on fish identification techniques to address the issue of fish species biodiversity, loss of biodiversity and fishery diversity.
- **Integration** of different methods comprising the classical and advanced taxonomy tools was developed in the past to achieve the common objective of precise and meticulous species identification.
- **Inventorisation** and deposition of all the available finfish species in the National and International Repositories for the research in taxonomy and establishment of a systematic catalogue.
- **Pollution**: Untreated sewage, garbage, fertilizers, pesticides, industrial chemicals, plastics. Most of the pollutants on land eventually make their way into the ocean, either deliberately dumped there or entering from water run-off and the atmosphere. Not unexpectedly, this pollution is damaging the entire marine food chain - all the way up to humans.

- **Unsustainable fishing**: Around 90% of the world's fisheries are already fully exploited or overfished, the catch of juveniles also pose danger to the diversity of fishes. Unsustainable fishing practices are the biggest danger to ocean life and habitats. Untargeted fish catching methods brings about large quantities of fishes and other fauna that leads to loss of the species.
- **Inadequate protection**: Oceans cover over 70% of our planet's surface, but only a tiny fraction of the oceans has been protected: just 3.4%. It is observed that the vast majority of the world's few marine parks and reserves are protected in name only.
- **Tourism and development**: Around the world, coastlines have been steadily turned into new housing and tourist developments, and many beaches all but disappear under flocks of holiday-makers each year.
- **Shipping**: Heavy traffic is leaving its marks of oil spills; ship groundings, anchor damage, and the dumping of rubbish, ballast water, and oily waste are endangering marine habitats around the world.
- **Oil and gas**: Important reserves of oil, gas, and minerals lie deep beneath the seafloor. However, mining and drilling for these pose a major threat to sensitive marine environments and species.
- **Aquaculture**: Fish farming is often regarded as the answer to declining wild fish stocks. But the farming of fish is actually harming wild fish, through the pollution from the farms discharge, escaped farmed fish, increased parasite loads, and the need to catch wild fish as feed.
- **Climate change**: Coral bleaching, rising sea levels, changing species distributions - global warming and climate change are already having a marked effect on the oceans. Policies are needed to deal with these phenomena, and to lessen other pressures on marine habitats already stressed by increasing water temperatures and levels.
- **Invasion of alien species**: The introduction of harmful aquatic organisms to new marine environments is believed to be one of the four greatest threats to the world's oceans. Those species are described as 'invasive' if they are ecologically and/or economically harmful.

Fishes are of immense value for human consumption, hence they are to be valued, nourished and conserved. Fish as well as fisheries forms the economic as well as social backbone of Indian society. Unfortunately, over dependence and overexploitation of these naturally bestowed resources has led to a heavy fall in the number and in turn affect the biodiversity of the system. These provide recreational, physiologic and aesthetic values to the people of interest. Fisheries have a great way to go as the income generated from these resources has shown a great demand in the future. This has been a resource of exchange in capital, investment and livelihood for majority. Fish culture, processing, trade and marketing has been providing with sufficient job opportunities for the common man. Various fishery agreements international as well as domestic have been of immense importance. Institutes and researchers are greatly indebted to nature for the scientific information collected from various research activities.

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CHAPTER

02

Biology of Mullets - Revisited

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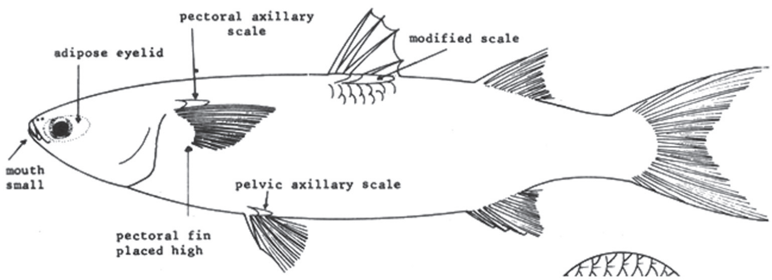
Members of the family mugilidae commonly known as mullets are one of the commercially important teleosts found in the coastal waters of the World. They have a Worldwide distribution including tropical, subtropical and temperate seas. Apart from inhabiting coastal and offshore waters, many mullets inhabit part or whole of their lifetime in coastal lagoons, lakes and even rivers. Mullets are moderate to large sized fishes reaching a maximum size of 120 cms. SL, but commonly reaching 30 cms. These fishes have a sub-cylindrical body, head often broad and flat dorsally. They have two widely separated dorsal fins. The first dorsal has 4 spines and the second one is with an unbranched ray and 6 to 10 branched rays. The pelvic fins are sub-abdominal with one spine and five branched rays. The anal fin has 2-3 spines and 8-12 branched rays. Lateral line is absent. Adults have ctenoid scales. The mouth is of moderate size with small labial or missing teeth. Their gill arches are long and they have a muscular stomach with a long intestine.

Taxonomic studies

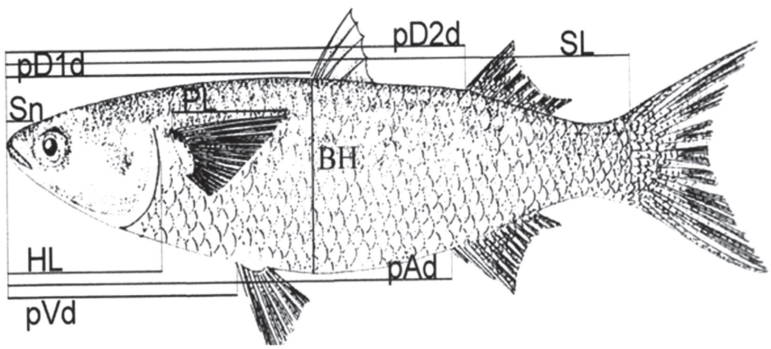
Thomson (1997), Eschmeyer & Fong, (2015), and Eschmeyer (2015) have done exhaustive work on systematics of mullets. Vide Eschmeyer (2015), there are 20 genera and 71 species. As of 2017, there are 75 species within the order Mugiliformes in the World (Thomson ,1977, Eschmayer & Fong, 2017). Currently there are conflicts on taxonomy of mullets at the generic level as well as the species level.

The taxonomy of mullets is mainly based on external morphology, meristics, morphometrics and the structure of some internal organs. Dentition, number of pyloric caeca, alimentary canal, otolith, morphology of the cephalic lateral line canals, pharyngo-branchial organs, pigmentation and melanophore pattern, are the characteristics used by many in taxonomy and identification of adults and fry. The adipose eyelid which is a fatty deposition on the head around the eyes, generally transparent and mostly well developed in adults is mentioned in most of the taxonomic keys and descriptions. The pyloric caeca can be of some taxonomic importance especially among different genera. Their number varies from 2 to 46 (generally between 5 and 8). The teeth are equally important in taxonomy. The teeth may be a single row or many rows and the shapes also vary from ciliform, setiform, caniniform, bicuspid, tricuspid etc. The head is equally important. The position and relationships of the different anatomical elements such as jaws, nostrils, lips and eyes, operculum and preorbital bones, jugular spines etc. aid in taxonomy. The preorbitals, a pair of triangular bones situated obliquely in front of the eyes are very useful in taxonomy. So also, the position of nostrils is equally useful in taxonomy. The presence or absence of axillary scales also aid in taxonomy. Among the meristic characters, the number of scales in the lateral series, the transverse scale count, the number of spines and rays in the fins are used in taxonomic study of these fishes. Morphometric differentiation of mullets such as the linear measurements are equally important along with molecular genetics or geometric morphometrics. The mullet taxonomy which is in a crisis can be tackled by an integration of all the above. Concerning phylogeny of the family Mugilidae, it appears exceptionally obscure at both the intra and inter-specific levels, it is extremely challenging to distinguish among species (Papasotiropoulos et al., 2002). The effectiveness of the CO1 gene in Mitochondrial DNA has been promising in distinguishing morphologically cryptic organisms including fishes. Chew et al., (2018), successfully conducted a study on identification of mullet species of Setiu Wetland, Malaysia using the approaches of morphological assessment using CO1 gene analysis.



GREY MULLET

Morphometrics



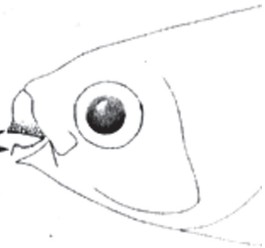
Pyloric caeca

DISTINGUISHING CHARACTERS OF SIMILAR SPECIES OCCURRING IN THE AREA :

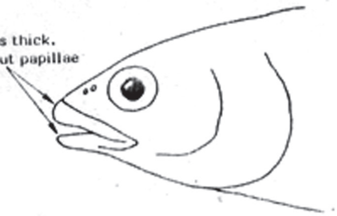
Crenimugil crenilabis: lips with several rows of papillae (no horny projection); preorbital bone without anterior notch; lateral line scales 38 to 40 (34 to 36 in O. labiosus).

Agonostomus species: lips thick, without any ornamentation; interorbital space convex; 2 anal fin spines (3 in O. labiosus).

All other species of Mugilidae have no ornamentation on lips.



Crenimugil crenilabis



Agonostomus species

Oedalechilus labiosus

SIZE :

Maximum: 40 cm; common to 20 cm.

GEOGRAPHICAL DISTRIBUTION AND BEHAVIOUR :

In the area, recorded from the Red Sea, the Aldabra, Seychelles and Laccadive Islands and from Sri Lanka. Elsewhere, from the Andaman Islands to Indonesia, Australia and Marshall and Mariana Islands.

Occurring in coastal waters, mainly in coral reef areas.

PRESENT FISHING GROUNDS :

Mainly coral reef areas.

CATCHES, FISHING GEAR AND FORMS OF UTILIZATION :

Separate statistics are not reported for this species.

Caught with gillnets, liftnets and seines.

Morphological characters helping in taxonomy

Distribution

The mullets are distributed in coastal regions of tropical, subtropical and temperate areas. Mullets are distributed approximately from 42R”-degree N to 42R” S. They are found in marine, inshore waters, lakes, estuaries and fresh water systems. Since mullets are euryhaline, they can tolerate salinities from 0 to 80 ppt., inhabiting hypersaline to brackish water lagoons, estuaries and fresh water systems (Gonzalez-Castro,2007). The biogeography and distribution of mullets remain unclear mainly because of the difficulty in separating species based on morphological characters. However biogeographic characterization is essential for developing ecological and conservation planning. Recent advances in molecular, phylogenetic and phylogeographic analysis provide new tools for better understanding of the distribution and the biogeographic pattern of mullets of the World.

Food and feeding habits

The Grey mullets have always been described as mud eaters, iliophagous, detritus feeders, deposit feeders and interface feeders (Brustle,1981). This is mainly because the diet of majority of mullet species is based on the organic matter present in the bottom sediment. They can also exploit benthic invertebrates, green filamentous microalgae, as well as plankton. While feeding, the mullets angle their heads downward, protract the premaxillaries and scrape the surface of the sediment. They take a mouthful of sediment and associated food items. (Odum, 1970, King, 1988). After working on the material between the pharyngeal bones, they reject some particles through their gills and mouth. The toothed lips help in scrapping microbial films, the pharyngeal teeth help in removing large sediment particles from the oral cavity and the densely packed gill rakers help in retaining finer particles. A two chambered stomach with a powerful gizzard helps in breaking cell walls and the long intestine facilitates digestion of plant materials. The organic content in the upper layer of the sediment ranges from 10 to 250 mg./gm. dry weight.

The stomach contents of mullets are a fine compact paste without microscopic details. When the contents are observed under low power, only the largest prey such as the red larvae of chironomid midges and green filamentous algae are observed amidst sand grains, mud and detritus. When observed under high power, we can observe highly diversified and abundance of single celled algae and a few copepods. A standard method of analyzing the stomach contents is as follows. The stomach contents are first mixed with 70% ethanol. (1:3, sample - ethanol rates) and stirred. A subsample is taken and observed under high power for identification of microscopic algae. The process is repeated several times and the number of species counted. At this point, the sediment sample is stained with Bengal Rose to make evident transparent invertebrates and count them under a dissecting microscope. The presence of filamentous algae, sand and detritus are recorded. A small subsample of the stomach content in ethanol may also be preserved without staining for future work. However, such examination does not give a full picture since the heterotrophic microbes are seldom detected or quantified accurately. Complex methods using stable isotope ratios and fatty acid markers are modern tools in dietary studies.

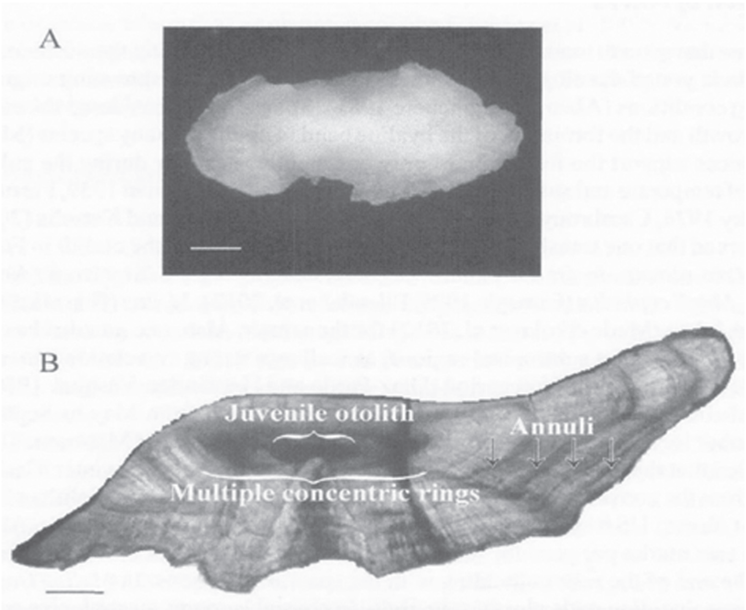
The food and feeding of the larvae are entirely different compared to the adults. In the larvae, the mouth opens three days after hatching. Even though very little is known about the food of larvae in nature the diet of hatchery reared larvae is known. Post larvae measuring 10-30 mm. TL usually referred to as fry are primarily zooplankton feeders in all species of mullets studied. Harpacticoid and cyclopoid copepods form the main prey of mullet fry in brackish water environments, whereas cyclopoid copepods, cladocerans and rotifers dominate the food of fry living in oligohaline and freshwater environments. The prey in general range in length between 700 –

1000 µm.

After recruitment to estuaries, juveniles of 20-55 mm length undergo a gradual transition from planktonic carnivory to benthic diet (de Silva,1997). The amount of plant materials and detritus increase steadily and the fish larger than 40-50 mm total length have an adult diet. The stomach contents of mullet fingerlings larger than 8 cms. is dominated by sand, detritus, microalgae and polychaetes. There are also a few mullets that feed on surf diatoms such as *Liza richardsoni*, *Liza ramnada*. *M.cephalus* is capable of feeding on zooplankton and phytoplankton when these occur in dense blooms.

Age and Growth and methods of studying the same

Growth is understood as the increase in length or weight generated by physiological processes and it is directly related to age. Environmental factors like temperature, availability of food, salinity and photoperiod influence mullet growth. *M.cephalus* has the greatest growth rates compared to other species. The annual migrations of mullets to coastal water from estuaries for spawning induce large variations in the growth rate that can change year after year with age as also with the biotope. Added to this are also other variations due to the long spawning period and the sexual physiology. Populations that are denied access to the Ocean for breeding and therefore do not spawn may exhibit greater length and weight showing that the energy used for gonad maturation may be used for somatic growth. The most frequently used method is the interpretation and counting of growth zones or of "stop growth annuli" which appear in the scale. Other hard parts of mullets such as otoliths, operculum, fin rays, and other methods such as tagging and length frequency distribution of a population (Peterson method) have also been used simultaneously with scale reading to get



authentic data. Generally, the scales used for age determination are situated under the first dorsal fin or the middle part of the body or at the extremity of the pectoral fin. The annuli (winter rings, marks, breaks or checks) which are the boundaries between two successive growth zones) are formed annually. However, there are some practical problems in age determination using the scales in mullets compared to other fishes since the markings on the scales are not always visible. In general, the rate of growth is highest during the first and sometimes the second year of life and noticeably slows down after sexual maturity. A linear relationship exists between scale radius and body length and between otolith radius and body length (Thomson,1951). This makes it possible to construct individual growth histories from the widths of scales or otolith increments. Female mullets grow faster than the males.

Sexuality and Reproduction of mullets

Mullets are heterosexual or gonochoristic. Cytological evidence of sexual differentiation begins in *M.cephalus* at lengths over 15 cms. SL. Normally adult females are larger than males. Males mature earlier and are smaller in size compared to females. There is however no sexual dimorphism and it is impossible to distinguish males from females, except the bulge of the belly of the females having growing ovaries. It has been observed that the girth of adult females (mature females) tend to increase by 3 cms. during the spawning season contributing to their selection in the nets. Female mullets are thought to be isochromal spawners, i.e. producing a single clutch of eggs per year. However, an individual may not release all eggs at once. A soft pressure applied near the vent brings out a drop of milt in case the males are ripe. Mullets are oviparous wherein the individuals shed their gametes into the water and fertilization is external.

Male reproductive system

The testes are tubular, longitudinal and paired. They are suspended in the cavity by mesenteries and lie lateral to the gas bladders. Spermatogonia occur along the entire length of the tubular organ. The morphology of the testis along with the fact that spermatogenesis takes place in enclosed cysts precludes monitoring of the actual development of the sperm. The stage of gonad maturity according to the shape of the testis and the condition of milt inside can be categorized into six stages. 1 immature, 2 mature, 3 ripening, 4 nearly ripe, 5 ripe, and 6, spent. Mature sperms are stored in the ducts surrounding each testis (vas deferens) and connecting to the urogenital pore (sperm duct) in a fluid called milt. Milt can be extruded from the urogenital pore by applying pressure to each side of the abdomen in an anterior to posterior direction. This process is called “squeeze check”. The actual procedure is as follows: after being anaesthetized, the male is turned upside down and the abdomen is gently squeezed three times between the thumb and the fore finger, from mid body to the urogenital pore. If no milt is extruded, the fish is recorded as negative. If milt is extruded the male is staged as a +1, +2 or +3 depending on whether the amount of milt which came out is scanty or copious.

Female reproductive system

Ovaries are paired and hollow consisting of two ovarian lobes separated by a septum. The lobes are joined near the urogenital pore. A number of oviferous folds project into the ovarian cavity which are lined by the germinal epithelium and which contain nests of oogonia. In *M. cephalus* it was observed that more than 83% of the specimens above 20 cm had become sexually differentiated. Total length at 50% maturity is as low as 22/24 cms. (male /female) which correspond to an age of two years.

Stages of oocyte development in mullets

Oogonia are small cells with a large nucleolus in the center and are observed in immature specimens or in post spawning females. The process which involves the transformation of oogonia to oocytes is called oogenesis. The stages in oogenesis are briefly described below.

a. Previtellogenic stage (primary growth stage)

In this stage, in mullets oocytes reach a diameter which varies from 50 to 200 µm, polyhedral in shape and rounded nucleoli. At the peri nucleolus stage concomitant with the growth of the oocytes, the nucleus increases in size to form the germinal vesicle.

b. Cortical alveolar stage (secondary growth stage)

The oocyte measures from 200 to300 µm. In this stage the endogenous vitellogenesis starts. The zona radiata, an acellular vitelline envelope which develop around the oocyte, continues to differentiate and increase in complexity throughout the oocyte growth.

c. Vitellogenesis (3 stages)

In this stage, the extraovarian proteins are processed and packaged into oocyte yolk proteins and are accumulated in fluid filled yolk globules. These globules fuse centripetally forming a continuous mass of fluid yolk during post vitellogenic maturation. Yolked oocytes of mullets have a range of 350-800 µm. diameter.

d. Maturation, Germinal vesicle migration.

At this stage the GV migrates towards the periphery of the oocyte and the nuclear envelope dissociates. (GV break down). Hydration of the oocytes occur just before the spawning. Hydration takes place when the mullets migrate to coastal area from the estuaries and the hydrated oocytes may vary from 900-1000 µm. in diameter.

e. Post ovulatory follicle

Once the oocytes are ovulated or released, the follicular cells remain in the ovary and constitute the post-ovulatory follicle, which also shows clear evidence of recent spawning.

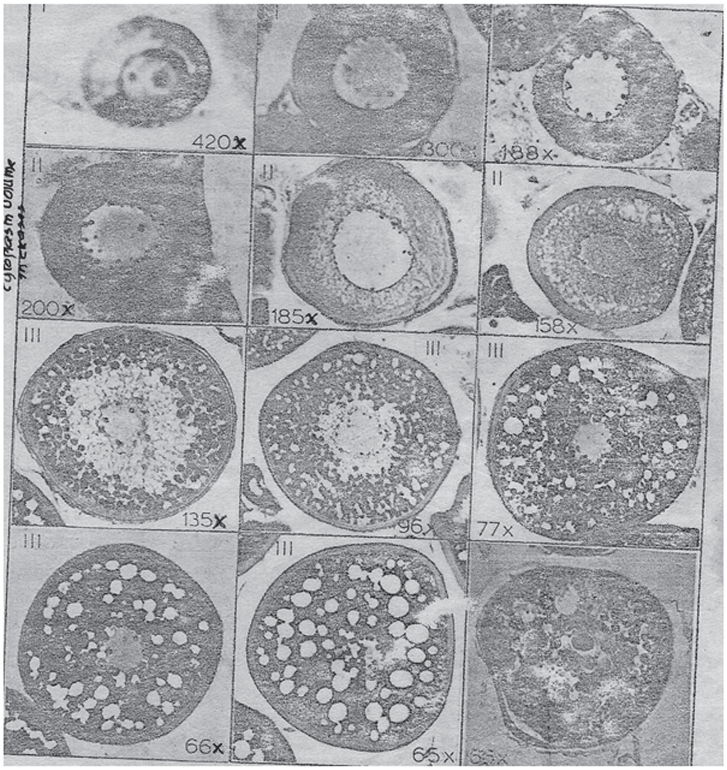
f. Atretic follicle

Atresia is oocyte degeneration that may occur at any stage of ovarian development. In this stage a series of vacuoles of various sizes will appear within the oocytes. The oocytes start breaking also.

Ovarian maturity stages

Four to seven stages have been traditionally described in Mugilidae

1. Virginal. very small translucent. At the microscopic level only oogonia and incipient primary oocytes occur.
2. Immature, slightly smaller, ovary weight 1.3 gm and light pinkish coloured. Microscopically primary growth oocytes, with compact and organized lamellar structure.
3. Incipient maturity, ovarian weight 10-20 gms. Colour pale yellow to dark yellow – two stages of oocytes, primary growth oocytes and cortical alveoli oocytes. The females are considered mature at this stage.
4. Advanced maturity. Ovaries occupy half to ¾ of abdominal cavity. 30 to 280 gm. weight. Dark yellow to orange. Oocytes appear visually
5. Spawning – running stage: Ovaries occupy the entire abdominal cavity, translucent, hydrated oocytes. Can be seen with naked eye.
6. Spent: Flaccid ovaries, highly vascularized, notably shrinking- occupying 25% of abdominal cavity
7. Resting: flaccid, reddish or greyish in colour – 4-10 gm.



Stages in oocyte development of Mullets

Fecundity:

Fecundity estimates are based on ovaries at stage IV. Fecundity or potential fecundity is estimated by removing three pieces of ovary (0.1 - 0.2 gm) from anterior, middle and posterior portions. These are rehydrated and weighed and all oocytes counted. P.F is estimated by the mean number of yolked oocytes per gram weight that is YO/G and the ovary weight OW

PF = YO/G x OV. W

For *M.cephalus* the fecundity 5 lakhs to 15 lakhs

Gonado-somatic index

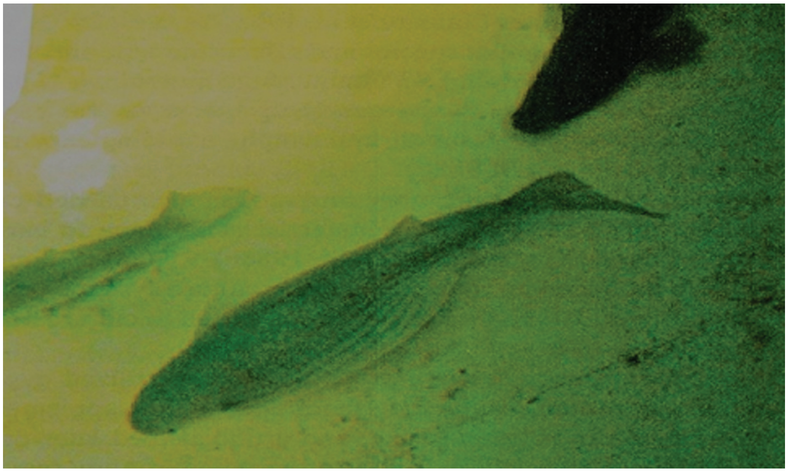
GSI is an efficient estimate of the physiological state of gonads. GSI can be defined as GSI = OW.100/BW here OW is the ovarian weight in gms. and BW is the body weight. The male gonads are very small compared to the ovaries. In *M.cephalus* from Japan the ovarian weight was 20% of body weight whereas the testicular weight was only 11%. Males mature earlier and are smaller in size compared to females

Neuroendocrine function of reproduction

The hypothalamus, pituitary and gonads are particularly influenced by environmental factors such as photoperiod and water temperature. The control of reproduction is with these organs. Fish adenohypophysis synthesizes at least eight different hormones of which two are directly related to reproduction in fishes, the FSH and the LH. Reproduction in fishes is controlled by the actions of the above hormones. They stimulate gonadal steroidogenesis and are involved in oocyte maturation, ovulation and spermiation.

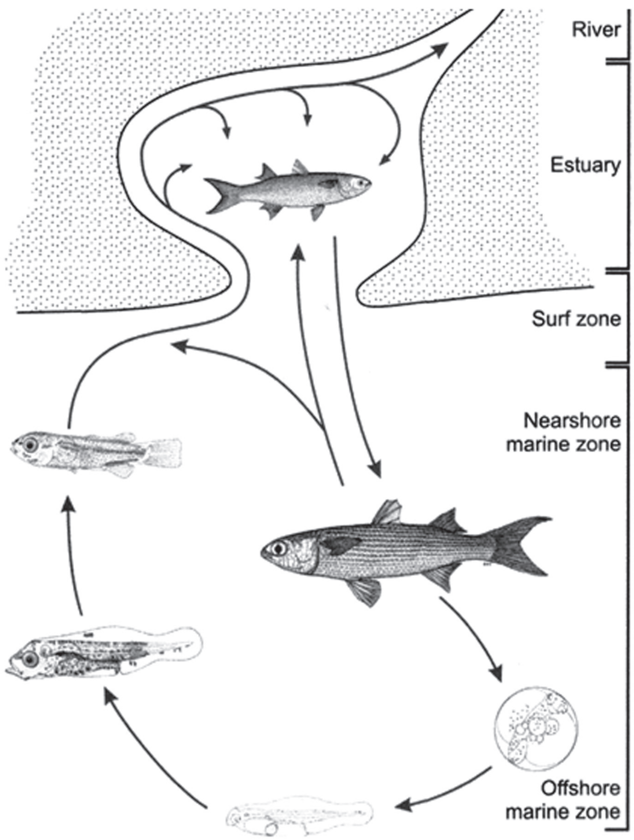
Spawning

Mullets spawn in different geographical areas at different times of the year. Spawning of each species takes place depending on an optimal temperature range.



A female mullet with swollen abdomen and ready to spawn

Migrations in fish happens on two reasons, the search and selection of suitable areas to migrate and the adoption of the appropriate environmental conditions that will mark the beginning of migration. All mullets are catadromous. They migrate to the sea to spawn. Before maturity the mullets stay predominantly in the coastal systems of rivers and lakes. As maturation begins they migrate to the sea where they complete maturation and spawning. About 2-3 months after the beginning of the reproduction period, there is an onshore migration of the post flexion larval stage followed by a temporary occupation of the surf zone as early juveniles. Once near the coast, they move in schools to coastal lagoons or lakes, estuarine waters or sometimes even reach fresh water, several kilometers away from the coast. These migrations are repeated every year. There are also records of mullets living permanently in sea water systems. Since mullets are euryhaline they have the ability to adopt to changes in salinity during migration. This is helped by many organs such as gills, kidney and the alimentary canal. The osmotic regulation performed during migration is also controlled by endocrine system and hormones.



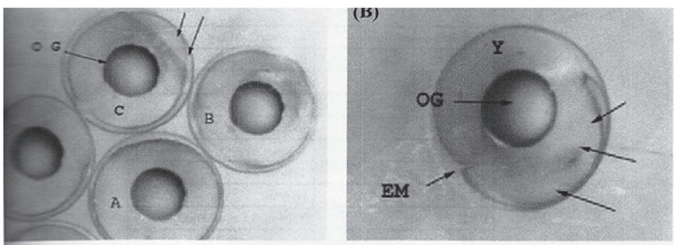
Migration of mullets

Observations on spawning behavior of Mullets in nature are few. After migrating to high saline coastal waters , large numbers of fish were observed schooling but scattered into small groups generally made up of one large female and a varying number of smaller but active males. Mullets are oviparous wherein the individuals shed their gametes into the water and fertilization is external. The spawning process as observed in hatchery conditions is as follows. Spawning is heralded by a violent quivering of the males which lie parallel to and touching the female. The first release of a few ripe eggs stimulates the males to liberate spermatozoa. The female then responds with an explosive and continuous release of eggs. Fertilization is external.

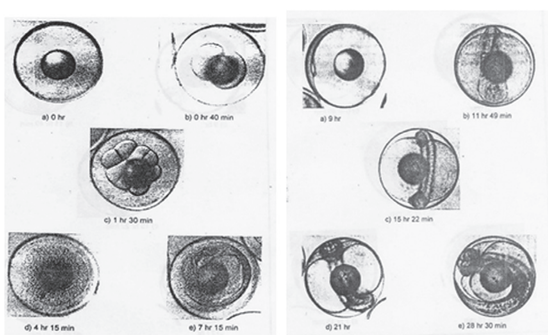
The embryonic phase:

This phase describes the development of the eggs from spawning till hatching

The morphology of the eggs before fertilization is described in many mullets studied. The unfertilized eggs are pelagic, spherical and transparent and the chorion is smooth. There is one large golden yellow oil globule that makes the egg extremely buoyant. The eggs are not adhesive (0.93 µm. Dia.). Shortly after fertilization the cytoplasm becomes thickened at the animal pole of the egg where the nucleus occurs. The cells divide in a meroblastic fashion (cells form only at the animal pole). In about 50 minutes after fertilization, the first meroblastic division occurs. The developing embryos are visible after 15 hours post fertilization. The hatching of *M.cephalus* is evident in 36-38 hours after fertilization at 24R”C.



Eggs of *Mugil cephalus* (X31). (A) Unfertilized egg A), Fertilized egg B) Germinal disc stage C) Morula stage



Stages in development of eggs

Early larval development

The developmental stages of several mullet species have been described by many. This has been studied due to success in induced breeding techniques on many of the species. At hatching the fish becomes a larva. Most of the fish larvae have a yolk sac providing nourishment for the newly hatched larva (yolk sac or prelarva).

The newly hatched larva float upside down. Liao, (1978) gave a full description of the larval development of *M.cephalus*. Newly hatched larvae of *M.cephalus* vary in length between 2.2 - 3.5 mm length. Egg development and hatching are temperature dependent. At an age of 3-4 days, the mouth opens and the larva starts taking planktonic food. The larval period lasts till the fin rays reach the adult compliment when the juvenile stage begins. In about 25-28 days the scales and fin rays are well formed.

Artificial propagation

Eleven species of mullets have successfully been propagated artificially in many parts of the World. Mullets do not spawn spontaneously in captivity. Methods to build up brood stocks of mullets in captivity are also well developed. Induced breeding protocols are available in many publications. Hormones used vary from Pituitary homogenate, HCG, LH Rh a, Steroids, etc. A method of assessment of the state of maturity of egg in mullets is available called *live ovarian biopsy* (Shehadeh et al.,1973). The intra ovarian oocytes are removed in vivo from an unanesthetized female with the help of a polytene catheter and a sample of eggs from the middle portion of the ovary is sucked out. The oocytes collected are washed and preserved in a solution of 1% formalin in 0.6 % Nacl. They are then placed in a small Plexiglas plate and measured using an ocular micrometer. Average egg diameter is calculated and maturity determined. The spawning is induced in females at the tertiary yolk globule stage (600 μm).

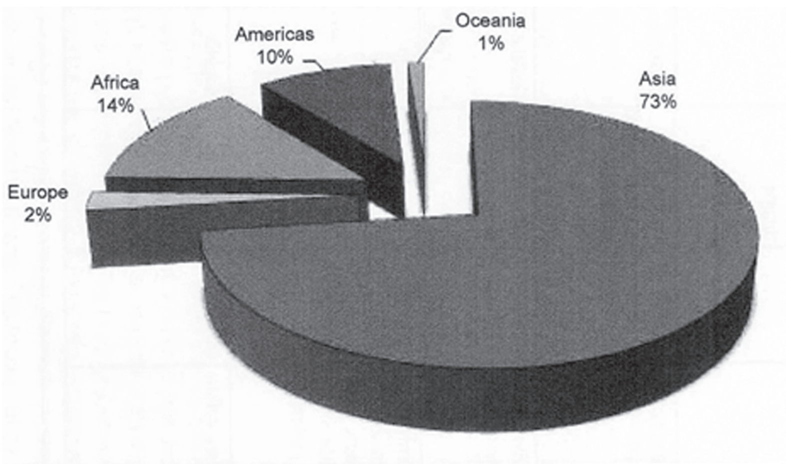
The females of M. *cephalus* are primed with commercial Carp Pituitary homogenate @ 20-40mg. /Kg. body weight followed by a resolving dose of LH RH a @ 100mg./kg. body weight administered 24 hrs. later. The males are sometimes administered with a dose of 17 Methyl testosterone for thinning of milt. Hormone treated female is left in a tank with 2-3 ripe males. Females spawn naturally in the tank and they are immediately fertilized by the males. The fertilized eggs are collected and left for hatching. The fecundity of *M. cephalus* is 8 lakhs - 2.7 million eggs per female. After hatching, the larvae are stocked in densities of 20-25 larvae / liters to start with and fed with rotifers (s-type) at densities of 10-20 rotifers/ml. Addition of cultured phytoplankton helps in growth of the larvae as well as keep the rotifers healthy. From day 12, *Artemia* nauplii are introduced as food for the larvae. Cultured copepods are also eagerly accepted by the larvae. Mortality of the larvae are high on the 2-3 day and 8-11 days. The use of hatchery produced larvae for culture is not viable for culture, since the cost of production is high.

Predation

Mullets are predated by piscivorous fish, crocodiles, sharks, birds and even by dolphins.

Mullet fisheries and culture:

Mullets are of great importance in fisheries and aquaculture. History tells that Egyptians captured mullets. Records of culture/capture of mullets by Romans, their culture in Italian *'vallis'* the Egyptian "hoshas" and Hawaiian ponds, in Indonesian *'Tambaks'*, *'Bheris'* of West Bengal are well documented. Mullets are grown/cultured in extensive, semi intensive and intensive systems. Vide FAO records mullet production was 698,293 tonnes in 2013, mainly 80.2% from capture fisheries (560150 tonnes) but with 138143 tonnes from aquaculture (FAO,2015). Capture fisheries for mullets are reported from 103 countries. China is the leading producer of mullets from Asia. Asia produces 73% of mullets and India is in the third place. 71 species of mullets are subjected to capture and culture. Mullet culture is practiced in the Mediterranean and Black sea region and Southeast Asia. Africa has the highest production among continents. Egypt, Indonesia, Republic of Korea, Taiwan and Israel are leaders in mullet culture. Other mullet producing countries are Tunisia in Africa, Guyana, Hongkong, Iraq, Saudi Arabia, Singapore, Greece, Italy, Spain, Ukraine, China and India. *M.cephalus* is the species used for culture in majority of countries since its growth rate is high. Capture methods of Mullets vary from seines, encircling nets, trammel nets, cast nets, dip nets and also pelagic trawling, spearing, rod and line, shooting arrows etc. Dolphins are found to help fishermen in catching Mullets by schooling them.



e 16.2. Mullet production from capture fisheries in 2013 by continent (%) (data from FAO

Fry collection for culture

Major sources of fry for culture are from wild since artificial propagation of mullets have not been commercially developed.

Fish traps, scoop nets, cast nets, seines and push seines also are used Worldwide. Fry are fragile and tend to get damaged during transport. Oxygen pack transport is safe. Acclimatization before release is a must and lessens the shock and increases survival.

Products from mullets

Mullets are sought after for their roes (ovaries). The Mullets roe is expensive and sold either fresh or salted. Mullet roe is known in different names in different countries. It is called Boutargue in Arab whereas in South east Asia it is called 'karasumi' and in Egypt as 'batarekh'. Ripe females are cultured in special ponds in Taiwan. The roe collected from them are vacuum packed, bee waxed or grated dry. The optimum weight of the roe collected from three-year-old females is around 300gms. In Taiwan male testes are sometime eaten raw.

Mullets are also filleted, salted or hot smoked and packed. Mullet gizzards are also eaten. Raw mullet fingerlings are eaten raw in Hawaii

Parasites and diseases

Mullets are fragile fishes and are easily prone for secondary infection with bacteria. Fungal infections are also common in culture systems. Parasite infection from microsporidians, myxosporidians, copepods, isopods, nematodes, cestodes are also common in natural as well as cultured mullets.

Raw mullet roe and testes

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CHAPTER

03

Ecolabelling in Fisheries: Boon or Bane in Improving Trade?

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Introduction

This document is a collation of information, mainly from FAO documents on fisheries ecolabelling (FAO, 2001; Sainsbury, 2010; Washington and Ababouch, 2011). Fish is one of the most highly traded commodities in the world, and as a natural resource, there is worldwide concern about long-term sustainability of the resources. Ecolabels are a new and growing feature of international fish trade and marketing. They have emerged in the context of increased demand for fish and seafood, and a perception that many governments are failing to manage the sustainability of marine resources adequately. Many mechanisms to ensure the sustainability of fish stocks have been introduced by international bodies which are binding on national governments. These include:

- The United Nations Convention on the Law of the Sea (UNCLOS) (1982);
- The FAO Code of Conduct for Responsible Fisheries (the Code) (1995);
- The United Nations Fish Stocks Agreement (1995); and
- Various regional fisheries management organizations (RFMOs).

The RFMOs facilitate international cooperation at the regional level for the conservation and management of highly migratory and straddling fish stocks. At the national level, governments are attempting to embed the principles and goals of the Code– now in its second decade of implementation – into their national fisheries management policies (FAO, 2009a). However, they are having varying degrees of success. Disappointment with the pace of regulatory measures to curb overfishing and to improve fisheries sustainability has led environmental groups to develop alternative market-based strategies for protecting marine life and promoting sustainability. These private market mechanisms are designed to influence the purchasing decisions of consumers and the procurement policies of retailers selling fish and seafood products, as well as to reward producers using responsible fishing practices. Ecolabels are one such market-based mechanism.

The FAO Guidelines for the Ecolabelling of Fish and Fishery Products from Marine Capture Fisheries state that voluntary standards, including environmental standards, should not distort global markets and should not create unnecessary obstacles to international trade. Under the general principles and definitions, they state that any ecolabelling scheme should be consistent with inter alia the World Trade Organization (WTO) rules and mechanisms.

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What is an Ecolabel ?

Ecolabelling is a market-based tool to promote the sustainable use of natural resources. Ecolabels are seals of approval given to products that are deemed to have fewer impacts on the environment than functionally or competitively similar products. The ecolabel itself is a tag or label placed on a product that certifies that the product was produced in an environmentally friendly way. The label provides information at the point of sale that links the product to the state of the resource and/or its related management regime. Sitting behind the label is a certification process. Organizations developing and managing an ecolabel set standards against which applicants wishing to use the label will be judged and, if found to be in compliance, eventually certified. The parent organization also markets the label to consumers to ensure recognition and demand for labelled products. The theory is that ecolabels provide consumers with sufficient information to enable them to recognize and choose environmentally friendly products.

A range of ecolabelling and certification schemes exists in the fisheries sector, with each scheme having its own criteria, assessment processes, levels of transparency and sponsors. What is covered by the schemes can vary considerably: bycatch issues, fishing methods and gear, sustainability of stocks, conservation of ecosystems, and even social and economic development. The sponsors or developers of standards and certification schemes for fisheries sustainability also vary: private companies, industry groups, NGOs, and even some combinations of stakeholders. A few governments have also developed national ecolabels.

The first fisheries ecolabelling initiatives appeared in the early 1990s and were largely concerned with incidental catch, or bycatch, during fishing. For example, the “Dolphin-Safe” label was based on standards developed by the United States NGO Earth Island Institute and is focused on dolphin bycatch in the tuna industry (rather than the sustainability of tuna stocks).

Marine Stewardship Council (MSC)

One of the first scientifically developed ecolabelling schemes, the MSC was set up by the WWF and Unilever in 1997, but has been independent of them for more than ten years. The MSC is arguably the most comprehensive fisheries certification scheme in that it covers a range of species and deals with all aspects of the management of a fishery. MSC sets the standard for the ecolabel through its board, supported by a Technical Advisory Board.

The MSC has qualified for membership of the ISEAL (International Social and Environmental Accreditation and Labelling Alliance) as being consistent with its “Code of good practice for setting social and environmental standards”. The MSC has two standards: on “sustainable fishing” and on “seafood trace ability”. The MSC owns the standards against which independent third-party certifiers assess conformance. Its “Fisheries Assessment Methodology”, and “standardized assessment tree” focus on three pillars: independent scientific verification of the sustainability of the stock; the ecosystem impact of the fishery; and the effective management of the fishery. All three pillars are assessed on the basis of a range of indicators. Aspects related to the species, the fishing gear used, and the geographical area, are all included in the assessment. A study by Caswell and Anders (2009) concluded that it is the scheme most often referred to in the seafood industry media, and has variously been described as the "industry standard". Another recent study (MRAG, 2009) revealed that a significant number of retailers and brand owners refer to the MSC in their sea food sustainability procurement policies.

Some 150 fisheries around the world are engaged in some stage of the MSC assessment process (including pre-assessment) (MSC, 2009). Fifty-six fisheries have so far been certified. The MSC claims to cover "about 7 per cent of the annual global wild harvest" of fish and seafood, accounting for 42 per cent of the global wild salmon catch and 40 per cent of the global white fish catch. However, not all fish from a certified fishery will end up with the MSC label attached. The actual volume of MSC-labelled product on the market as a proportion of overall traded fish products is likely to be considerably less significant in terms of global trade. While there are no robust statistics on the proportion of MSC-labelled products on the global market, FAO estimates suggest that the volume of MSC- labelled products on the market may only be statistically significant in the context of specific European markets. Ina study carried out for FAO in 2007, Poseidon Ltd. estimated MSC products as then accounting for 0.3 per cent of globally traded seafood by value. Sales of MSC-labelled fish and seafood of an estimated US$1.5 billion is minor when seen against a fisheries commodity market amounting to US$101 billion in global export sales (FAO, 2010).

As of late 2009, more than 2 500 MSC-labelled products were available on the market (MSC, 2009); this is double the number (1 200) on sale at the beginning of 2008,and more than four times the number (600) available in early 2007,24 showing just how dynamic the market for certified fish and seafood is. Today, MSC products are sold in52 countries around the world.

Friend of the Sea

Friend of the Sea (FOS) has its origins in the Earth Island Institute. Set up in 2006, its founder is also the European Director of Dolphin Safe. It covers both wild and farmed fish and its criteria also include requirements related to carbon footprint and "social accountability". Certification is based on the sustainability of the stock, rather than whether the fishery is sustainably managed. Its certification methodology is based on existing official data in terms of stock assessment. Friend of the Sea says it will not certify stocks that are "overexploited" (based on FAO definitions of levels of exploitation), fisheries using methods that affect the seabed and those that generate more than 8 percent discards. Certification is undertaken by independent third-party certifiers. Friend of the Sea claims to be "the main sustainable seafood certification scheme in the world" covering some 10 per cent of the world's wild capture fisheries. It should be noted that 80 per cent of the 10 million tonnes of landed FOS certified product from capture fisheries (8 million tonnes) comes from Peruvian anchovies. Again, it is unclear what proportion of that product ends up as labelled products for retail sale. There are about 600 FOS products (including fish oil and omega-3 supplements) sold in 26 countries28 and covering 70 species both from wild capture and aquaculture.

Marine Aquarium Council

The Marine Aquarium Council (MAC) was established in 1998 and by 2001 had adopted a standard and process to certify the wild capture and subsequent treatment of fish for the ornamental aquarium trade. In 2004, a standard for live fish for human consumption was developed because many of the operators and communities involved with the aquarium trade are also involved in the trade of live fish for consumption. However, this standard for live fish for human consumption was not formally adopted by the MAC and no fisheries have been certified for this trade.

Other NGO schemes

Other NGO-driven schemes include KRAV, a Swedish NGO that specializes in organic farming but which has recently developed a “standard for sustainable fishing” and Naturland in Germany also with a background in certifying organic farmed seafood but now with a “Scheme for the Certification of Capture Fishery Project”, which includes social, economic and ecological sustainability criteria. To date, Naturland has only certified one fishery (Nile perch from Buboka in the United Republic of Tanzania).

Fishing company in-house ecolabels

A few individual fishing companies have created their own ecolabels. For example, the Spanish group Pescanova, one of Europe’s largest fishing companies, which fishes globally and has interests in the processing sector, has created a logo that appears on a limited range of its packaged products. The logo states that the fish concerned has been caught in a way that “preserves the aquatic and marine ecosystem for maintaining the quality, diversity and availability of fish resources for today and future generations”. This in-house scheme claims to be based on the Code.

Fishing industry association ecolabelling schemes

The Japan Fisheries Association, an umbrella group for some 400 fishing companies, founded the Marine EcoLabel- Japan (MEL) in December 2007. The MEL operates as a non-profit part of that association. It could be seen as a response to a developing interest in ecolabelled fish and seafood in the Japanese market. Indeed the stated rationale behind the label was to “respond to the situation proactively and establish their own ecolabelling scheme, which is most suitable to the situation of the Japanese fisheries”. As of January 2010, only three fisheries have been certified to the fledgling label. It is likely to have significance only in the Japanese market.

Public ecolabelling schemes

Recently, some public authorities, most notably the Government of France and Iceland, have set up their own ecolabels. The Government of France has chosen to create its own national ecolabel and related certification scheme. This decision was based on a feasibility study undertaken in 2008 by the French authority, FranceAgriMer. As part of that process, it examined existing private ecolabels, including for consistency with the FAO Guidelines for the Ecolabelling of Fish and Fishery Products from Marine Capture Fisheries. It concluded that, of the existing ecolabels, only the MSC was fully compliant with those guidelines. However, it also concluded that the MSC model would not fit all fisheries. It decided to adopt a public framework to meet the needs of its fishing industry as defined by the feasibility study; a scheme that was less costly than the MSC, easily recognized by consumers, and one that was consistent with the FAO guidelines but went beyond them with the inclusion of social and economic criteria.

The public label does not preclude the certification of French fisheries to other private ecolabels. Indeed, certification to other labels has been encouraged; a number of French fisheries are currently in assessment with the MSC.

Most of the descriptions provided in this document refers most often to the MSC and FOS, as the two schemes that – on the basis of their international scope, the number of fisheries certified and the claimed volumes of certified fish and seafood products entering international markets – stand out as the most internationally significant private voluntary ecolabelling schemes.

Principles and Criteria for Sustainable Fishing of MSC

At the centre of the MSC is a set of Principles and Criteria for Sustainable Fishing which is used as a standard in a third party, independent and voluntary certification programme. These were developed by means of an extensive, international consultative process through which the views of stakeholders in fisheries were gathered.

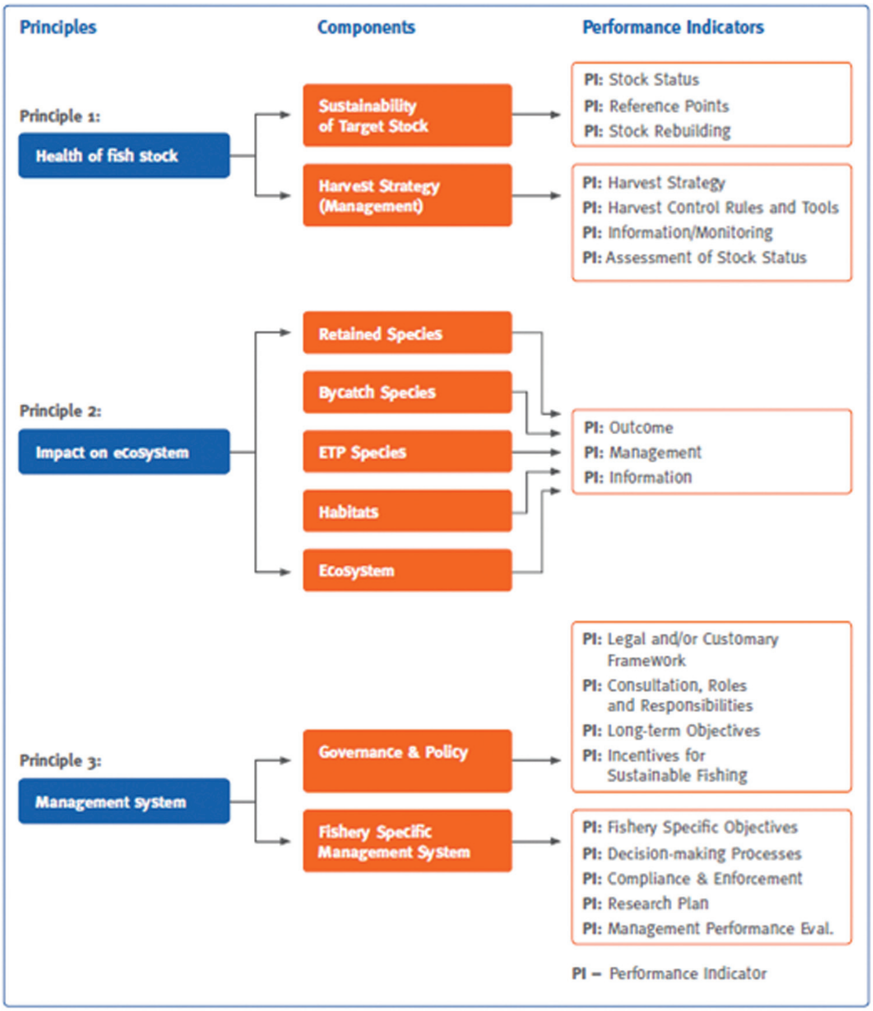

Fig. 1. Principles and Criteria for Sustainable Fishing of MSC

These Principles reflect a recognition that a sustainable fishery should be based upon:

- The maintenance and re-establishment of healthy populations of targeted species;
- The maintenance of the integrity of ecosystems;
- The development and maintenance of effective fisheries management systems, taking into account all relevant biological, technological, economic, social, environmental and commercial aspects; and
- Compliance with relevant local and national local laws and standards and international understandings and agreements.

MSC's Risk Based Framework

The MSC began work to develop suitable methodology to assess data-limited fisheries in 2005. A series of expert workshops and consultations were undertaken. These led to the development of a set of risk-based tools referred to at the time as the Guidance for the Assessment of Data-Deficient and Small-Scale Fisheries. In early 2008, a pilot project commenced to test these tools using seven pilot fisheries from around the globe, resulting in the Risk-Based Framework (RBF). In February 2009, Version One of the RBF was released for public consultation and provisional use by certifiers. Following this consultation and a subsequent final revision, the RBF was integrated into the MSC Fisheries Assessment Methodology (FAM), Version Two, and approved by the MSC Technical Advisory Board and MSC Board of Trustees for official use as of 31 July 2009. The RBF can now be used in any fishery assessment that uses the default assessment tree in the FAM as its basis.

Criteria for FOS Ecolabel

Friend of the Sea Criteria are categorical in nature and based on the most restrictive and worldwide acknowledged and accepted definition of 'sustainable fisheries'. On this matter Friend of the Sea has taken in due consideration requests from stakeholders, such as NGOs and traditional and artisanal fisheries, for a more limitative definition of 'sustainable fisheries'.

A Sustainable Fishery, of FOS is one that:

1. Does not insist on an overexploited, depleted or data deficient stock;
2. Has no impact on the seabed;
3. Has lower than average discard level;
4. Complies with all local national and international legislation
5. Apply a management system that assures the respect of above mentioned requirements.

An example of legal criteria of FOS is shown below.

Price premium – myth or reality ?

4 – LEGAL CRITERIA: TAC, IUU, FOC and legislation

n°	Requirement	Level
	The fleet fishing the audited product must :	
4.1	Respect Total Allowable Catches (TACs), if in place. Last year's TAC has been respected or, in case it has not been respected, at least 2 out of the past 3 years TACs have been respected.	Essential
4.2	Include NO IUU (Illegal, Unreported, Unregulated) fishing vessels.	Essential
4.3	Include NO FOC (Flag Of Convenience) fishing vessels.	Essential
4.4	Respect national and international legislation, in particular legislation related to the reduction of the environmental impact of the fishery (such as, but not limited to: - vessel registration, - mesh size, - net size, - minimum size, - distance from the coast, - by-catch reduction measures, - no fishing on protected habitat - verify onboard equipment and absence of banned fishing gears and methods, chemical substances, explosives - log book if compulsory)	Essential

There is only spotty evidence of price premiums accruing to certified fish and seafood. Research by the URI Sustainable Seafood Initiative (Asche, Insignares and Roheim, 2009) found price premiums at the retail level but acknowledged that this did not necessarily imply that any premium would accrue to fishers. At the 2009 OECD/FAO Round Table, some participants reported, if not price premiums, then less price volatility at the ex-vessel stage of the supply chain. Often, this was related to more direct supply relationships. The MSC's recent publication, Net Benefits (MSC, 2009),which describes the experiences of the first 42 fisheries to be certified, concludes that the main beneficiaries of price premiums have been smaller-scale artisanal fisheries (all in developed countries) selling into niche markets. The price premiums described are all associated with more secure supply relationships, either with restaurants or, to a lesser extent, supermarkets.

Impact of Ecolabels on trade

It is difficult to estimate the volume of ecolabelled certified products on the international market. The MSC and FOS claim 7 per cent and 10 per cent respectively of world's capture fisheries – when put together they account for less than one-fifth of wild capture product. It is certain that the real volume of traded ecolabelled products is significantly less than that. Indeed, of the MSC's 6 million tonnes of seafood landed from certified fisheries, only about 2.5 million tonnes ends up carrying the MSC label (MSC, 2009). A significant proportion of FOS-certified fish goes into products such as fishmeal and fish food that will not end up as labelled products on supermarket shelves(although the farmed fish they feed may do). Other schemes in existence currently cover fairly insignificant volumes of product. Overall, the market presence of ecolabelled products is likely to be modest, and significantly lower than the publicity surrounding such products would suggest (Washington and Ababouch, 2011).

Boon or Bane ?

In a world in which the demand for fishery products are increasing in leaps and bounds, and the pressure on the natural resources are rising, ecolabelling appears to be a possible way to bring about a greater degree of control and sanity in the system. The increasing proportion of aquaculture in the production system for aquatic products is also being addressed by global organizations. Following on from its involvement in the certification of sustainable forestry (Forestry Stewardship Council - FSC) and wild-capture fisheries (Marine Stewardship Council - MSC), the WWF has developed standards for aquaculture certification, with an emphasis on eliminating the negative environmental and social impacts of aquaculture called the Aquaculture Stewardship Council (ASC). It has organized a range of round tables involving aquaculture producers, buyers, NGOs and other stakeholders in an attempt to develop standards for aquaculture certification. The first ASC certificate is expected to be issued in 2012.

A recent study evaluating the effectiveness of certified seafood showed that though there are debatable shortcomings, for a consumer, it is reasonable to buy certified seafood, because the percentage of moderately exploited, healthy stocks is 3–4 times higher in certified than in non-certified seafood (Froese and Proelss, 2012).

CHAPTER

04

Stable Isotope Analysis - A Novel Methodology in Fishery Biology Analysis

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Introduction

Isotopes are atoms with the same number of protons and electrons but differing numbers of neutrons. Isotopes are denoted by an atomic "formula." For example, the most common isotope of carbon is 6C12, where 12 is the atomic mass, or the sum of neutrons and protons, and 6 is the atomic number (number of protons/electrons). Stable isotopes are defined as those that are energetically stable and do not decay; thus, they are not radioactive. An isotope tends to be stable when the number of neutrons (N) and the number of protons (Z) are quite similar (N/Z d" 1.5). There are roughly 300 stable isotopes, over 1200 radioactive isotopes, and only 21 elements that are known to have only one isotope (Hoefs 1997). The relative natural abundance commonly used isotopes in ecology are depicted below.

Table 1. Relative abundances of stable isotopes most common in ecological research

Element	Isotope	Abundance	Relative Mass difference	International Standard	Absolute abundance of the standard ($R_{standard}$)
Hydrogen	^{1}H ^{2}H	99.985 0.0155	100	Vienna standard mean ocean water (VSMOW)	^{2}H:^{1}H = 0.00015576
Carbon	^{12}C ^{13}C	98.892 1.108	8.3	Vienna Pee Dee Belemnite (VPDB)	^{13}C:^{12}C = 0.0112372
Nitrogen	^{14}N ^{15}N	99.635 0.365	7.1	Atmospheric nitrogen	^{15}N: ^{14}N = 0.0036765
Oxygen	^{16}O ^{17}O ^{18}O	99.759 0.037 0.204	12.5(^{18}O: ^{16}O)	VSMOW in water; VPDB in carbonates	VSMOW = 0.0020052 VPDB =0.0020672
Silicon	^{28}Si ^{29}Si ^{30}Si	92.21 4.70 3.09	7.1(^{30}Si: ^{28}Si)	NBS-28 -	
Sulphur	^{32}S ^{33}S ^{34}S ^{35}S	95 0.75 4.21 0.014	6.3(^{34}S: ^{32}S)	Vienna- Canon Diablo meteorite troilite (VCDT)	^{34}S: ^{32}S = 0.00045005
Iron	^{54}Fe ^{56}Fe ^{57}Fe ^{58}Fe	5.82 91.66 2.19 0.33	3.7(^{56}Fe:^{54}Fe)	Average terrestrial & lunar rocks	^{56}Fe:^{54}Fe = 15.7028
Strontium	^{84}Sr ^{86}Sr ^{87}Sr ^{88}Sr	0.56 9.87 7.04 82.53	1.1(^{87}Sr:^{86}Sr)	US Geological Survey	^{87}Sr:^{86}Sr = 0.709249

The use of stable isotopes in ecology and hydrology depends on its variations in the natural systems. These natural variations of environmental isotopes (18O, 2H etc.) are usually very small. Isotopes function as natural dyes or colours, generally tracking the circulation of elements. Isotopes trace ecological connections at many levels, from individual microbes to whole landscapes. Isotope colours mix when source materials combine, and in a cyclic process that ecologists can appreciate, the process of isotope fractionation takes the mixed material and regenerates the sources by splitting or fractionating the mixtures (Fry, 2008).

Isotopic fractionation

Stable isotope variations result from isotope fractionation which occurs during some physical and chemical processes. Examples of physical processes which could lead to isotopic fractionation are evaporation of water or condensation of vapor. During evaporation, the residual liquid is enriched in the heavier isotope molecule because the lighter molecule moves more rapidly and hence has a greater tendency to escape from the liquid phase i.e. there is a difference in the volatility between the two molecular species. Chemical fractionation effects occur because a chemical bond involving a heavy isotope will have a lower vibrational frequency than an equivalent bond with a lighter isotope. The bond with the heavy isotope will thus be stronger than that with the light isotope. Fractionation may occur during both equilibrium and non equilibrium chemical reactions. During non equilibrium of irreversible reactions, kinetic fractionation leads to the enrichment of lighter isotope in the reaction product, because of the ease with which the light isotope could be broken.

Chemical equilibrium reaction can be discussed with the reaction

$$C^{16}O_2 + H_2{}^{18}O \text{ ”! } C^{16}O^{18}O + H_2{}^{16}O$$

The equilibrium constant for this reaction is

$$K = (C^{16}O^{18}O)\,(H_2{}^{16}O)/\,(C^{16}O_2)\,(H_2{}^{18}O)$$

If the oxygen isotopes are randomly distributed in the reactants then,

$$K = a = ({}^{18}O/{}^{16}O)_{CO2} / ({}^{18}O/{}^{16}O)_{H2O}$$

where a is the isotopic **fractionation factor.**

For example, $a_{CO2\text{-}H2O}$ at 25°C is equal to 1.042, which means that CO_2 is 4.2% enriched in oxygen-18 with respect to water.

The fractionation factor for all processes where the processes proceed so slowly that equilibrium conditions are practically established at the inter phase of the two phases, is simply the ratio between the vapor pressure of the lighter component (P) and the heavier component (P‘). It is also defined as the ratio between the isotopic compositions in the liquid and the vapor phases.

$\alpha_D = 1.08$

$\alpha_{18O} = 1.009$

This indicates that the vapor is depleted by 8 % in deuterium and 0.9 % in oxygen–18 relative to liquid water. Condensation is predominantly an equilibrium process whereas evaporation normally occurs under non equilibrium condition.

d Definition

The average abundance of oxygen-18 in various compounds is close to 2000 ppm. This number varies from compound to compound because of the fractionation effects mentioned above and the oxygen-18 content varies from 1900 to 2100 ppm. However it is difficult to determine accurately the absolute oxygen-18 content in every compound through routine analysis. Fortunately for most studies, it is sufficient to know the relative abundance with respect to standard. These relative isotope concentrations can be determined easily with great accuracy by a differential isotope ratio measurement using a mass spectrometer. The relative difference is called d value and is defined as

$$d = (R_{sample} - R_{std})*10^3/R_{std}$$

The d value is generally expressed as part per thousand or per mil (‰).

A sample with d18O value of +10 per mil is thus enriched in 18O by 10 per mil relative to the standard.

The isotopes in ecological research are dominated by the lighter elements because they dominate biological compounds and because the percent increase in mass caused by the addition of a single neutron is greatest for these elements. Iron and strontium are among the heaviest isotopes used in ecological studies, and currently their use is not common.

Natural Variations

Carbon and ä^{13}C

Carbon has two stable isotopes: the more common 12C and the minor isotope 13C, with the primary international standard being V-PDB, derived from the carbonate skeleton of a Cretaceous cephalopod (Pee Dee Belemnite). The natural ä13C variations of terrestrial material span a 100% range, from biogenic methane and other reduced carbon compounds with very negative values, through soft animal and plant tissues, to carbonates with ä13C values just into the positive portion of the ä13C scale. The largest reactive pool in the carbon cycle is marine dissolved inorganic carbon (DIC), which controls the ä13C of carbonate secreting organisms; both lie close to 0%. One of the seminal discoveries in stable isotope ecology was that terrestrial plants using disparate photosynthetic pathways could be differentiated using ä13C (Smith and Epstein, 1971). C3 plants generally have values of around 23‰ to 22‰, whereas C4 plants have a ä13C range of about 21.8‰ to 27‰, with the resulting soil organic ä13C reflecting the respective photosynthetic process (Michener and Lajtha, 2007). The disparity between the ä13C of C3 and C4 plants is stark, given that the precursor for both photosynthetic pathways is atmospheric CO2. The difference is caused by the fact that the ribulose-1,5-bisphosphate carboxylase (Rubisco) catalyst involved in the C3 pathway strongly discriminates against 13CO2 compared with phosphoenolpyruvate (PEP) carboxylase, the C4 catalyst. The ä13C of CAM (crassulacean acid metabolism) plants overlaps with C3 and C4 plants, with a range of 21‰ to 22.2‰ (O'Leary, 1988).

Another application of stable isotopes has been to derive water-use efficiency (WUE) estimates of plants. Both WUE and the ä13C of plants are controlled by intracellular carbon dioxide concentrations; this led Farquhar et al. (1982) to demonstrate that the ä13C of plant tissue could be used as a reliable indicator of WUE. Investigations of WUE in plant systems using the isotope approach are numerous, for example Marshall and Zhang (1994) modelled WUE in deciduous and evergreen plants over a large altitudinal gradient. In the marine environment, photosynthesis proceeds via the C3 pathway; however, the ä13C of marine plants and algae do not resemble terrestrial C3 plants, since here the carbon source is mainly DIC rather than atmospheric carbon dioxide. Marine phytoplanktons have a wide range of ä13C values from about 23‰ to 21.8‰, the lighter values associated with higher latitudes (Rau et al., 1982). Freshwater phytoplanktons encompass a similar but slightly larger range of ä13C values. Marine and freshwater vascular plants macroalgae have a wide range of ä13C reflecting the use of carbon dioxide or HCO3 for photosynthesis (Maberly et al., 1992).

Nitrogen and ä^{15}N

Nitrogen has two isotopes, the more common 14N and the minor isotope 15N. By far the largest reservoir of nitrogen above the geosphere is atmospheric nitrogen, and its uniform isotope ratio is the reason for its choice as the international standard for ä15N, atmospheric isotope reservoir (AIR). Nitrogen fixation involves very little nitrogen isotope fractionation, such that N-fixing plants have ä15N values very close to 0%. Non-nitrogen-fixing plants have a slightly more varying range of ä15N compositions, depending on their particular source of nitrogen. The successive oxidation steps involved in nitrification are associated with varying amounts of fractionation, which is kinetically controlled. Given that most of the organic nitrogen in soils is slowly converted into ammonium, this is generally the rate-determining step in the nitrification process and the resulting nitrate is quite similar in terms of ä15N to the organic starting materials. However, when large amounts of ammonium are available, the oxidation steps to nitrite and nitrate are rate limiting, and the nitrate formed may be depleted in 15N by up to 3.5‰. Denitrification back to molecular nitrogen gas involves a 15N depletion of up to 22‰. All the fractionations in the pedospheric part of the nitrogen cycle are heavily dependent on nitrogen concentrations. Synthetic fertilizers, since being produced from air via the Haber process, are close to 0‰. Volatilization of ammonium compounds to ammonia from manure, however, involves a fractionation of up to 24‰, such that the residue may be very 15N-enriched. This has proved quite useful in detecting sewage pollution (Costanzo et al., 2001).

Hydrogen (ä^{2}H) and oxygen (ä^{18}O)

Hydrogen has two stable isotopes – the minor isotope deuterium or 2H and the more common isotope protium or 1H. Oxygen has three stable isotopes, though the minor 17O is of less importance from an ecological standpoint; as with the other elements mentioned here, 16O is more common than its heavy counterpart, 18O. Both hydrogen and oxygen isotope scales use standard mean ocean water (V-SMOW) as their primary international standards. Ocean water is a fairly uniform 0‰ in terms of both ä2H and ä18O scales, with the exception of where there is mixing with freshwater or ice sheets. During both evaporation and condensation of water, the fractionation of hydrogen and oxygen isotopes are correlated, such that precipitation isotope ratios form a linear relationship which approximates ä2H =8 ä18O +10‰, called the global meteoric water line. As a result, there are strong spatial patterns of ä2H and ä18O in precipitation on a global scale, and seasonal patterns in the same location. Models have been put forward to predict the isotopic composition of precipitation at a given geographic location (http://www.waterisotopes.org). The natural range of waters is around 600%, stretching from the Antarctic ice which is close to 2500%, to over +100% in the Saharan basin lakes which are subject to extreme evaporation. The source of hydrogen for plants is local water, which enters the plant with negligible fractionation, such that bulk plant water ä2H is consistent with environmental water. In higher terrestrial plants, however, evapotranspiration in the leaf increases both ä2H and ä18O of plant cell water compared with environmental water. Organic compounds, particularly lipids, resulting from biosynthesis in plants are depleted in 2H compared with water.

Interest in the hydrogen and oxygen isotope systematic of plant tissues has been driven by the possibility of deriving historical climate data, and empirical correlations have been derived between tree ring cellulose isotope data and various environmental factors including temperature, humidity and rainfall. Hydrogen isotopes in animal tissues also reflect local precipitation, despite the complication of hydrogen incorporation via diet as well as drinking water. Given the complexity, detailed knowledge of how hydrogen isotopes are exchanged during tissue synthesis is still lacking.

Sulfur and ä^{34}S

Sulfur has four stable isotopes – 32S, 33S, 34S and 36S, with 32S and 34S being the most abundant (c. 95% and 4% respectively). The ä34S scale is measured with respect to Canon Diablo Troilite (V-CDT). The vast majority of natural samples fall into a range from 240% to +40%. Large deviations in ä34S are primarily caused by biologically mediated fractionation at low temperatures. In particular, dissimilatory bacterial reduction of sulphate to H2S creates large sulphur isotope effects, such that the ä34S of resulting sulphides can be up to 40%more negative than pre-existing sulphate. In contrast, there is little fractionation of sulphur isotopes during the assimilation of sulphate by both aqueous and terrestrial plants. Although marine sulphate is a very uniform+21%, sulphate uptaken by terrestrial plants is more variable, and depends on the underlying geology. Animals must ingest organic sulphur compounds and convert them as necessary, though minor isotope fractionation is involved. Thus, throughout various food-web studies, 34S-enrichments are often taken as evidence of a marine influence, and ä34S measurements have been used to trace marine nutrients in freshwater systems (MacAvoy et al., 1998).

Applications of Stable Isotope Approaches to Ecological Problems

Determining diet/food webs

Although some animals' diets may readily be determined by observation alone, more elusive species may require a more invasive approach. In some animals it may be possible to obtain regurgitated dietary material to study, whereas in others only gut content analysis (GCA) will be possible, which is obviously a destructive technique. The main disadvantage of these conventional techniques is that they all comprise 'snapshot analyses': they only provide a measure of what an animal has been feeding on most recently. Stable isotope analysis integrates diet over a longer time period, and offers an alternative approach which is often nondestructive and in many cases noninvasive.

It is possible to use a theoretical approach to calculate isotope fractionations for many simple chemical reactions; however, in the real, complex, biological world, an experimental/observational approach is more feasible. Merely subtracting the original delta value from the final delta value in a particular process gives a workable approximation, Ä of the total fractionation of the process. The effect for ä13C is much less, with carbon isotope ratios reflecting more the source of carbon, such that ä15N – ä13C plots are a useful graphical representation of simple food webs. The arithmetic difference in the nitrogen isotope ratio of consumer and diet (Ä15N= ä15Nconsumer - ä15Ndiet) has been termed the 'trophic enrichment factor' (TEF). TEFs have been calculated for many taxa, and though mean Ä15N for several compilations of taxa averages around +3% (Minagawa and Wada, 1984; Post, 2002; Vanderklift and Ponsard, 2003; Vander Zanden and Fetzer, 2007) in agreement with the earliest work (DeNiro and Epstein, 1981), the range of D15N is quite wide, and varies with the biochemical mode of excretion and diet C:N (Vanderklift and Ponsard, 2003). In some cases, for example large cetaceans, it is impractical to measure TEFs directly, and assumptions are made regarding a probable TEF for the consumer/diet in question. Diet is generally determined by stable isotope analysis of specific tissues, rather than that of the whole animal, and different tissues will partition isotopes by differing amounts, hence tissue-specific TEFs (i.e. ä15Ntissue - ä15Ndiet) have to be taken into account. Despite these complications, Ä15N has been used to make direct inferences about the diet of many consumers, and nitrogen stable isotopes have also been used to infer a variety of ecological parameters. For instance, the variance of stable isotope ratios has been used to derive a measure of trophic niche width (Bearhop et al., 2004). The ä15N value of a consumer relative to that of the base of the food web combined with the knowledge of TEFs provides a quantitative measure of the food chain length (Vander Zanden et al., 1999), which is not subject to the kind of errors involved in estimating the number of trophic levels based on the presence/absence of intermediate consumers.

The isotopic composition of an animal tissue reflects diet at the time of synthesis, and different tissues in the same animal have varying turnover rates. This provides an opportunity to obtain time-integrated dietary information. Turnover rates (and TEFs) are calculated using carefully controlled 'diet-switch' feeding experiments. These involve changing the feeding regime of a laboratory animal from an isotopically homogeneous diet to one which is isotopically disparate (e.g. from a C3-based plant diet to a C4 one). Tissues are sampled before the diet switch, and at regular intervals following the change to the new diet. In the C3–C4 diet switch example, ä13Ctissue is plotted against time, an exponential uptake curve is plotted and a half life is calculated. As an example, in one of the earliest such experiments, Tieszen et al. (1983) showed that the ä13C half-life in rat muscle is around a month, compared with a week for rat liver. Recently, the exponential-fit approach has been criticized for the assumption that these diet-switch isotope exchange reactions are subject to firstorder rate kinetics. Using an analogous methodology to disentangle radionuclides of differing half-lives, Cerling et al. (2007) have determined 'reaction progress variables' by linearizing the exponential decay curves. Such work has been validated by the observation that there can be more than one source pool with differing half-lives, and that this method provides more realistic diet reconstruction scenarios.

This approach is very useful, as it allows the researcher to look at changes in diet over time, using the isotopic composition of different tissues. As an example, for a small passerine bird, by measuring the ä15N and ä13C in blood and feathers, it is possible to glean dietary information from a few days (plasma) and weeks (red blood cells) ago, and from the time of the most recent feather moult, and all without sacrificing the bird. In contrast to the soft tissues mentioned above, many hard tissues (feathers, baleen, hair, fingernails, teeth) are metabolically (and therefore isotopically) inert once synthesized. Some of these – tooth collagen, for example – are grown incrementally, and can be tied to temporal parameters, such as growth annuli. Stable isotope measurements on individual increments allow a high resolution temporally explicit dietary history to be constructed. Careful measurements such as these have for instance elucidated long-term dietary changes in bowhead whales (Hobson and Schell, 1998), toothed whales (Mendes et al., 2007) and elephants (Cerling et al., 2009). Mixed models have been developed to determine diet based on stable isotope measurements, the principal requirement that the consumer assimilates diets which are isotopically disparate. For example, Inger et al. (2006) explored marine versus terrestrial dietary choices by light-bellied Brent geese at monthly intervals over a 16-month period. One of the obstacles in obtaining dietary information from an animal tissue is that using simple mathematical models a maximum of only n+1 dietary source can be elucidated from n isotope ratios. More advanced models (Phillips and Gregg, 2003) will provide a range of feasible solutions to systems where the number of sources is too large to provide a unique mixture of diets, but these models are parameterized with invariable figures for the isotope ratios of diet and TEFs. Recently, Bayesian models (Moore and Semmens, 2008; Parnell et al., 2008) have been proposed which incorporate uncertainty, and result in probability distributions for which the analyst can choose the most likely solution.

Animal migration

The study of animal migration is essentially an extension to dietary modelling as described above. As intrinsic markers, the stable isotope approach does not require initial marking of individuals; all that is required is that an animal moves from one isotopically distinct habitat to another. It is particularly informative for those animals which are too small to attach transmitters, for example insects and small passerines. In terms of carbon isotopes for instance, the ä13C disparity between freshwater and marine primary production has been used to detect anadromy in fish (Adams et al., 2008).

The relationship between temperature and ä2H precipitation affords the potential to map the migration of terrestrial animals at a fine resolution. The rationale for hydrogen isotope tracking of animals is as follows: (i) Temperature and rainout effects in the hydrological cycle provide a uniform relationship between ä2H precipitation and latitude, altitude and continentality. A description of hydrogen isotope fractionations in the hydrological cycle is given by Clark and Fritz (1999). (ii) There is a predictable relationship between a specific animal tissue of interest and ä2Hprecipitation (iii) The tissue sampled for hydrogen isotope analysis is metabolically inert once synthesized.

Feather keratin is metabolically inert once grown, and in North America, the positive relationship between ä2Hprecipitation (= geographic location) and ä2Hfeather has been used to good effect for elucidating the migratory behaviour of a number of passerine bird species (Chamberlain et al., 1997; Hobson and Wassenaar, 1997). Large compilations of ä2Hprecipitation data from global hydrological projects have been used to construct 'isoscapes' (Bowen and Revenaugh, 2003). Isoscapes are spatial distributions of isotope ratios incorporated into maps, which can be utilized to broadly predict the geographic location of growth of an individual feather. Europe, however, is topographically more complex than North America, and latitudinally shorter, which means that the range of ä2Hprecipitation is smaller and less predictable (Hobson et al., 2004). Nevertheless, there have been a number of successful investigations of European bird migration using hydrogen isotope measurements of feathers or claws (Bearhop et al., 2005). Where migration passes over areas differing in the relative proportions of C3 and C4 plants, the addition of ä13C increases discrimination (Neto et al., 2006).

There are other sources of variation in ä2Hfeather) which confound the use of stable hydrogen isotope ratios as a geolocation device. For instance, long-term climatic variations may cause temporal changes in ä2Hprecipitation, and differing metabolic effects among species may result in a species-specific correlation between ä2Hprecipitation and ä2Hfeather. Thus, the 'map-look-up technique' for assigning geographic origins of populations using precipitation isoscapes and an equation involving ä2Hprecipitation and ä2Htissue is attracting some criticism (Wunder and Norris, 2008). This technique still remains popular because of its easy implementation; it is nevertheless useful in the early stages of experimental design. Isoscapes based on control conspecific or analogue individuals from known locations allow a direct comparison. Ironically, one of the first isoscapes (Hobson et al., 1999) is a classic example of this, constructed from the isotope analysis of Monarch butterflies raised in known locations across the eastern United States. This provided a template from which Monarch butterflies could be geographically assigned with some accuracy.

Isotope additions

It is possible to buy chemical compounds from commercial companies which are enriched in the heavy isotope such that the isotope ratio $R > 0.99$. These compounds have obvious advantages over radioactive tracers in tracer studies in that they are nontoxic and do not require licensing. They are generally used to investigate the routing of materials and chemical transformations which occur along the way. The simplest experiments involve just adding a labelled compound to a system, and then analysing the different products to acquire knowledge about the location(s) of the products of reactions involving the labelled compound; more detailed experiments would obtain quantitative data on how the label is partitioned among the products. An example of this in the carbon cycle would be using 13C labelling to examine how carbon is allocated to different plant tissues, and eventually to components of soil. Similarly, 15N labelling has been applied to soil-plant systems. In particular, the 15N tracer has been used to elucidate the fate of different 15N-labelled fertilizers (Powlson and Barraclough, 1993) by measuring its abundance in the ammonium, nitrate, organic N and plant tissue. By measuring the 15N abundance over time, a measure of the loss of N derived from the fertilizer can be measured. Other examples of 13Cand 15N labelling out with plant and soil sciences include the application to stream basal food resources to evaluate the importance of these to consumers (Parkyn et al., 2005) and examining the fate of 13C-labelled phytodetritus among the oceanic abyssal benthic community (Witte et al., 2003).

A special example of isotope additions is that of doubly labelled water (DLW), which is water with enriched levels of 2H and 18O. The DLW method has been developed for studying the intake and loss of water and energy metabolism in animals. An animal is typically injected with DLW, weighed and blood samples are taken at the time of the injection and some specified time later. Loss of 2H in water over this period can be used to derive a measure of water flux rate through the animal. 18O is lost as both water and carbon dioxide, and thus the difference between the rate of loss of 2H and 18O is a measure of the carbon dioxide production rate, a measure of energy expenditure. DLW can be combined with other ecological measurements to investigate the energy budgets of animals in their natural environment and during specific activities, for example migration flights for birds (Kvist et al., 2001).

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CHAPTER

05

e DNA - A New Concept in Fisheries Research

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Introduction

Environmental DNA (eDNA) is defined as the genetic material obtained from a water sample containing no distinguishing signs of source macro-organisms. The method utilizes DNA which is continuously excreted by organisms into the surrounding environment through mucus, gametes, faeces, blood and other cells, and captures, analyses and obtains the nucleotide sequence of this DNA based on an environmental sample. eDNA analysis has emerged as a potentially powerful tool to access aquatic community structures. The inherent drawbacks in traditional approaches to monitor fish biomass/abundance in exploited waters can be overcome by employing eDNA techniques. Analysis of this eDNA can give us information on the organisms, their abundance and biomass through two approaches – eDNA barcoding and eDNA metabarcoding. In the former, specific species are targeted in samples using standard or quantitative PCR, and using traditional Sanger sequencing method. In the latter, the whole community is screened using multiple conserved primers and Next Gen Sequencing (NGS) is done. Studies suggest that eDNA metabarcoding outperforms traditional survey methods in terms of non-invasive sampling, sensitivity and cost incurred. There is now increased interest in using eDNA to supplement existing survey methods.

Status of research

Since 2012 there has been a plethora of studies on eDNA metabarcoding as applied in biodiversity conservation, fish community identification, fisheries management, invasive species, as well as in fish biomass/abundance estimations. eDNA approach has been reviewed by Hansen *et al*. (2018 *Fish and Fisheries*, 1-18). A total 25 research papers related to eDNA metabarcoding/ metagenomics by Indian authors are predominantly pertaining to the study of microbial biodiversity from food, soil and deep sea sediments (Jiang and Yang, 2017 *Current Science* 112(8): 1659-1664). Not a single publication related to such study in fish has been cited from the Indian context.

Metabarcoding is constrained by factors like PCR efficiency, primer tags and sequencing efficacy. Another limitation is lack of comprehensively cured reference databases for certain metazoans for assigning taxon to the OTUS (Operational Taxonomic Units). Future studies are needed to improve sampling strategies (selection of season, sampling location within habitat, etc.) and to understand the relationship between sequence reads and species density. Gaps in knowledge about the dynamic mechanisms relating to shedding of tissue into the environment and metabolism related processes which could also affect quantity of DNA released by an organism into the water have to be filled. Dynamics of eDNA under field conditions, such as patterns of release, degradation, and diffusion will have to be taken into consideration to get estimates of fish distribution and biomass/abundance based on eDNA.

Methodology includes seawater filtration, quantitative real-time PCR, library preparation, Next Gen Sequencing (NGS) and statistical analysis. Copy number of DNA could be quantitatively interpreted in terms of fish abundance and biomass. High throughput sequencing data analysis using the state-of-the art tools could throw light on family level abundance in general and species level abundance of fish in particular. However, the strength of the relationship depends on environmental parameters, such as water temperature, and technical parameters, such as the filter being used for capturing eDNA. Species biology, environment and filtration methods and other factors (e.g. extraction and fish ecology and spatial distribution) likely to interact and significantly influence eDNA concentration variation. Caution is needed when interpreting the patterns of eDNA concentration in practical contexts. Parameters such as detection limits in water samples, influence of microbial activities on eDNA degradation, sampling design, seasonal conditions, nature of eDNA and fish ecology should be considered in future studies before predicting fish abundance from eDNA in natural conditions.

A basic study design and sampling strategies are essential for estimation of biomass using eDNA surveys. The decision on sample number and density within various habitats is an important aspect whiling developing a statistical sampling strategy. Further, the relationship between fish density and eDNA abundance depends on, e.g. taxon- and age-specific shedding rates, specific eDNA degradation rates in the given environment, and non-local eDNA transported with sea currents; the effect of these factors has to be measured and taken into account while analyzing the data.

Potential advantages of eDNA over conventional approaches

Continuous ship-borne monitoring surveys are time-consuming and expensive. Generally they are invasive, selective and rely on some degree of subjectivity related to the taxonomic expertise of the monitoring personnel; further, problematic due to a general decline in taxonomic expertise and related difficulties associated with correct species identification especially across egg and juvenile life stages. On the other hand, collection and analyses of water samples for eDNA more cost-effective, sensitive and non-invasive for presence/absence surveys of species, in contrast to established monitoring techniques relying on catching whole organisms. As all organisms continuously shed DNA through their metabolic waste products (and gametes), the method has the potential to objectively identify either individual species using qPCR; or entire biological communities across taxonomic groups using NGS platforms. Moreover, species-specific DNA concentrations could positively correlate with biomass and abundance thus pointing to a large potential for many different quantitative monitoring applications.

Factors which control eDNA presence in a given environmental sample

Environmental effects on the production, persistence and transport of eDNA, especially in marine ecosystems, are keys to establish robust and reliable temporal and spatial relationships between recorded DNA and qualitative/quantitative monitoring data. With reference to body surface area and metabolism small adult/juvenile fish are likely to produce more eDNA than large adult fish. Temporal persistence of eDNA particles in water depends on whether it's in free state or encapsulated and the external biotic and abiotic factors. Persistence time of eDNA can be highly variable, such as from 1 day to 58 days; being shorter in marine and brackish environments when compared to freshwater, presumably due to difference in environmental factors or osmoregulation between fresh- and marine species. In sea eDNA particles are estimated to travel more than 600 km in a week, and are less affected in the near coastal areas than in high seas.

Main challenges

Five principal challenges which affect eDNA concentration and its applications include: (i) to find what we are looking for, (ii) spatial origin, (iii) relationship between eDNA and biomass/numbers, (iv) application in fisheries management and (v) other sources of eDNA. Concern on 'false negative' and 'false positive' is common. 'False positive' can occur from empty fishing nets, bottom sediments, discards and fish carcases. Low fish density in marine environment compared to freshwater poses challenge in presence/absence detections in the former; this entails relatively larger volume of seawater to be sampled for eDNA analyses. In marine environment currents dissipate eDNA from the source; hence chances of detection diminish depending on the distance from the fish sampling was done. Faster degradation of DNA and dilution further blockade effective utility. In open water system relation between eDNA and biomass/numbers is obscure; there is need for more understanding of fundamental biological and environmental processes related to eDNA, and statistical modelling framework to make quantification more feasible in future. eDNA does not provide direct information on the size, number, age, weight, life stage or fecundity – cannot be a standalone tool for stock assessment paradigm.

Improving eDNA analyses

Fish metabolism and eDNA production could be correlated, though such studies are lacking. Influence of physical, chemical and biological environment on eDNA of source organism need to be studied to improve quantitative aspects of eDNA-based monitoring. Oceanographic modelling of eDNA transport and detection is a promising area of research to improve our understanding of the complex interactions and dynamics of eDNA in marine systems. Best estimates of eDNA dynamics are currently from freshwater environment. Research focus should be more on understanding the basic processes of eDNA in marine environments, rather than the present focus on direct application.

Novel applications

eDNA analysis can be applied in ecosystem monitoring, assessment of life history and migration patterns, stock structure analysis, and diet and processed fish product analysis.

Way forward

There has been amazing advancement in technology from quantitative real time PCR to smart phone-powered sequencer, which would minimize many of the classical logistical and practical challenges of handling, storing and transport of environmental samples. Finally technological advancement has reached in automated real time DNA measurements as in Environmental Sample Processor (ESP), which is set to monitor a specific geographic location ranging from coastal to deep sea, and does everything right from regular water sampling and storing to real-time molecular analysis. ESP may be costly, but cost-competitive compared to extensive ship time for visual monitoring or to continuous collection of water samples. eDNA is under the influence of many physical, chemical and biological parameters, which need to be analysed. Its role in direct quantitative assessment is still challenging. Current focus of research in this field should be around relative strengths on detection of presence/absence, migration patterns and life history events, broad ecological understanding, taxonomic coverage and providing basis for ecosystem-based management. Despite the caveats, eDNA-based monitoring will continue to develop to have profound impact on futuristic fisheries research and management.

CHAPTER

06

Ecosystem Modelling for Reservoir Fisheries Management

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Reservoirs, covering more than 1% of the country's land surface are a growing resource in India with enormous fish yield potential and play a vital role in the Indian economy by its contribution to employment generation, income augmentation, foreign exchange earnings, food and nutritional security. The reservoirs have become the focus of future fisheries development plans in India. Unlike rivers which are under the threat of increasing environmental degradation, the reservoirs offer ample scope for increasing the fish production through the adoption of suitable management strategies.

Reservoir ecosystems are complexes of biotic and abiotic elements, which are interrelated by flows of energy, biomass and information to form a comprehensive network. This network has an extraordinary high connectivity and its complexity rises drastically with the number of elements, relations and nonlinear interactions (Grant and Swannack, 2007). Environmental modifications caused by human interventions causes detrimental consequences to aquatic resources, especially on fishes. Introduction of species in several aquatic systems causes changes in water quality and modification of natural food webs. Stock supplementation in reservoirs are compensatory management schemes for conservation as well as stock enhancement. Ecological models can depict such interactions and changes in the environmental factors and also simulate the dynamics of spatial and temporal patterns in ecosystems. A proper understanding of the ecosystem properties is thus critical to predict and manage the consequences of environmental variability and human impacts, such as those induced by fisheries targeting specific species and size-classes.

Ecosystem models (Ecopath with Ecosim) are being used worldwide as an effective method to systematically describe the aquatic ecosystems. Developing the ecosystem approach would be ideal for a country like India, which is characterized by multispecies fisheries. However complex it might be, the ecosystems models need to be built up by knitting together all the relevant historic data, and involving in the process, the training and education of the fishermen towards the adoption of ecosystem approach to fishing. Such models estimate the carrying capacity of the ecosystems and the biomass at each trophic level by taking into consideration the weather and hydrography of the ecosystem and fish biology. Ecological modelling provides a large set of different approaches to analyse drivers of systems dynamics and extrapolate developments. However, it also has to be applied critically. Besides their potential in basic research, ecological models can also be very helpful tools in decision-making processes.

Ecopath with Ecosim (EwE) is the most applied tool for modelling aquatic ecosystems globally, with over 500 models published to date. Ecopath with Ecosim has its roots in classic ecology. The Ecopath and Ecosim modelling tool (EwE) is composed of a core mass balance model (Ecopath, which is the Ecological Pathways Model) (Polovina 1984, Pauly et al. 2000, Christensen et al. 2005) from which temporal and spatial dynamic simulations can be developed (Walters et al. 1997, Christensen, and Walters 2004).This tool has been used to describe quantitatively aquatic systems and the ecosystem impacts of fishing (Christensen and Pauly 1993, Christensen, and Walters 2004). In this software suite, Ecopath describes instantaneous biomass flows through a web of functional groups (Polovina, 1984; Christensen and Pauly, 1992),Ecosim integrates those flows over time (Walters et al., 1997).

Polovina (1984) developed the first Ecopath model, Christensen and Pauly (1992) further developed the model to include fractional trophic levels to consider species that feed across a range of trophic levels. The trophodynamic simulation model Ecosim (Walters et al. 1997, Christensen et al. 2005) has introduced the capability to conduct multispecies simulations to explore ecosystem structure and functioning, the impact of fishing, policy exploration and more; a year later, the development of Ecospace, a spatially explicit simulation model, began (Walters et al. 1999, Christensen et al. 2005). This model provides a quantitative representation of the studied ecosystem or a snapshot, in terms of trophic flows and biomasses for a defined time period. The ecosystem has many functional groups, which can be composed of species, groups of species with ecological similarities or ontogenetic fractions of a species. The key principle of Ecopath is mass balance: for each group represented in the model, the energy removed from that group, for example by predation or fishing, must balance by the energy consumed, i.e. consumption.

Prey - Predator controls

Bottom up control in ecosystems refers to ecosystems in which the nutrient supply and productivity and type of primary producers (plants and phytoplankton) control the ecosystem structure. An example would be how plankton populations are controlled by the availability of nutrients. Generally bottom up control exists in reservoir ecosystems. Plankton populations tend to be higher and more complex in areas where upwelling brings nutrients to the surface. In bottom up control the amount of food consumed is linearly proportional to prey biomass and independent of predator biomass.In ecology, top down control refers to when a top predator controls the structure/ population dynamics of the ecosystem. The amount of food consumed is proportional to the product of the prey and predator abundances. There are many different examples of these concepts. It is not uncommon for populations to be influenced by both types of control.

Niche overlap

Numerous overlap indices have been suggested for quantification of how species overlap. Loman (1986) summarized different types of indices, and described their properties based on a number ofhypothetical examples. One presents the overlap between food types (prey overlap) and another the overlapbetween predators (Predator overlap). The indices scales from 0 (no overlap) to 1 (identical diet or predatorcompositions). A modification of the Pianka (1973) overlap index derived from the competition coefficients ofthe Lotka-Volterra equations are used in ECOPATH. Overlap indices can be used as tools for generation of hypotheses. Another area where niche indices may beuseful isin the aggregation process. Aggregation is an important area of model construction. A major criterion used for such aggregation has been diet composition, butinclusion of feeding aspectsonly, overlooking predator composition, leads to valuable information being unutilized. Aggregation can more sensibly be conducted by using both food and predator compositions, forinstance by calculating both the overlap indices (prey and predator) and then aggregating the groups that showmost overlap.These trophic indices helps in describing the *prey- predator relationships*, in comparing the effects of different types of gears and biomass flows in a reservoir ecosystem which are pre-requisites for management of fishery resources. It can validate anecdotal information on presence or absence and relative abundance of fish species in the reservoir ecosystem.

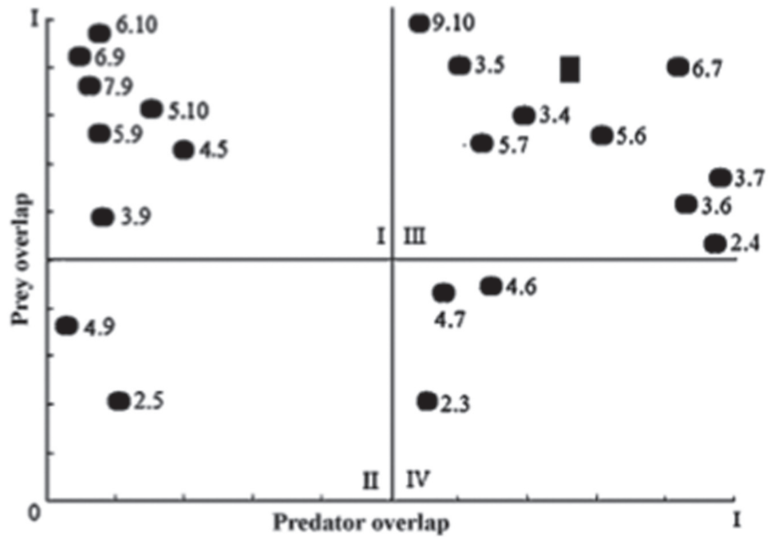

Fig. Prey vs. predator niche overlap plot.
(Khan and Panikkar , 2009)

Groups in the lower left of the figure have no overlap but groups on the the upper right corner have a high overlap for both predators and preys. The numbers represents the ecological groups as follows: (2) African catfish; (3) Indigenous catfishes; (4) Snake heads; (5) Mozambique Tilapia; (6) Nile Tilapia; (7) Pearl spots; (8) Major carps; (9) Dipterans; (10) Zoobenthos.

Trophic levels

Lindeman (1942) introduced the concept of trophic levels. In Ecopath, the trophic levels are not necessarily integers(1, 2, 3...) as proposed by Lindeman, but can be fractional (e.g., 1.3, 2.7, etc.) as suggested by Odum and Heald (1975). A routine assigns definitional trophic levels (TL) of 1 to producers and detritus and atrophic level of 1 + [the weighted average of the preys' trophic level] to consumers.

Following this approach, a consumer eating 40% algae (with TL = 1) and 60% herbivores (with TL = 2) will have atrophic level of $1 + [0.4 \cdot 1 + 0.6 \cdot 2] = 2.6$. The fishery is assigned a trophic level corresponding to the averagetrophic level of the catch, i.e. without adding 1 as is done for 'ordinary' predators.The trophic level is a dimensionless index.

Ecotrophic Efficiency (EE)

The ecotrophic efficiency (EE) is the fraction of the production that is used in thesystem, i.e. either passed up the food web, used for biomass accumulation, migration or export. Ecotrophic efficiency is difficult to measure directly; it varies between 0 and 1, and can be expected to approach 1 for groupswith considerable predation pressure. A value near to 0.0 is expected for a group, such as an apex predator, which suffers no predation and is not exploited by a fishery.

The part of the production that is not included in the EE is often called 'othermortality'. EE is dimensionless, and the entry of EE values is optional.The ecotrophic efficiency, EE, of a detritus group is defined as the ratio between the flow out of a detritus box, andthe flow into the same box. EE for detritus cannot be entered, it is always calculated.

Omnivory index

The 'omnivory index' was introduced in 1987 (Pauly et al., 1993a) in the initial version of the Ecopath II software.This index (OI) is calculated as the variance of the trophic level of a consumer's prey groups. Thuswhere, is the trophic level of prey j, is the trophic level of the predator i, and, is the proportion prey jconstitutes to the diet of predator i.

TLj TLi DCij

When the value of the omnivory index is zero, the consumer in question is specialized, i.e., it feeds on a singletrophic level. A large value indicates that the consumer feeds on many trophic levels. The omnivory index isdimensionless.The square root of the omnivory index is the standard error of the trophic level, and a measure of the uncertaintyabout its precise value due to both omnivory and sampling variability.

Net efficiency

The net food conversion efficiency is calculated as the production divided by the assimilated part of the food, i.e.,

Net efficiency = P/B / (Q/B · (1 - GS))

where P/B is the production / biomass ratio, Q/B is the consumption / biomass ratio, and GS is the proportion of thefood that is not assimilated.

The net efficiency can also be expressed

Net efficiency = Production / (production + respiration)

The net efficiency is a dimensionless fraction. It is positive and, in nearly all cases, less than 1, the exceptions beinggroups with intermediate trophic modes, e.g., groups with symbiotic algae. The net efficiency cannot be lower than the gross food conversion efficiency, GE.

Net system production

Net system production is the difference between total primary production and total respiration. As can be inferred from the discussion of ecosystem maturity, system production will be large in immature systems and close to zero inmature ones. Systems with large imports may have a negative system production. Systems production has the same unit as the flows from which it is computed, e.g., t · km^{-2} · year$^{-1.}$

System respiration/biomass

In an ecosystem, the ratio of total respiration (R) to total biomass (B) can be seen as a thermodynamic order function(Odum, 1971). Odum calls it the 'Schrödinger ratio', after the physicist E. Schrödinger who showed that biological systems, in the presence of thermal vibrations, must continuously pump out 'disorder' if they are to maintain the internal 'order'. Thus, the larger the biomass, the greater the maintenance cost. Whether biological systems(individual organisms, or ecosystems) tend to maximize their R/B ratio over evolutionary time or not is a matter of debate. The ratio has the dimension year-1, and can take any positive value. The R/B ratio is strongly impacted by the assumed fraction of the food that is not assimilated, see the basic input form. If the ratio is too high, this may be due to GS being too low. Thus the ratio indicates the "metabolic activity level" of a group. R/B ratios are expected to be within 1–10 year$^{"1}$ for fish and may be as high as 50–100 year$^{"1}$ for groups with higher turnover such as copepods.

System primary production/respiration

This is the ratio between total primary production(Pp) and total respiration (R) in a system. This ratio express the fate of the assimilated food. It is considered by Odum (1971) to be an important ratio for description of the maturity of an ecosystem. In the early developmental stages of a system, production is expected to exceed respiration, leading to a ratio greater than 1. In systems suffering from organic pollution, this ratio is expected to be less than 1. Finally, inmature systems, the ratio should approach 1; the energy that is fixed is approximately balanced by the cost of maintenance. The Pp/R ratio can take any positive value and is dimensionless. However, Christensen and Pauly (1993) comparing 41 Ecopath models found that P/R ranged from 0.8 to 3.2. The high ratio values were thought to have arisen because of the omission of bacterial activity that led to an underestimation of respiration.

System primary production/biomass

The ratio between a system's primary production (Pp) and its total biomass (B) is expected to be a function of its maturity. In immature systems, production exceeds respiration for most groups, and as a consequence, one can expect the biomass to accumulate over time. This, in turn, will influence the system ratio, which can be expected to decline. The system ratio behaves like that of individual groups; its dimension is time-1 and it can take any positive value.

Respiration/Assimilation Biomass

(RA/AS) < 1.0. The proportion of biomass lost through respiration cannot exceed the biomass of food assimilated. As a guideline, K selected species, which are expected to invest a relatively small proportion of energy intake in somatic and gonadal tissue production are expected to have RA/AS ratios close to 1.0. In contrast, r-selected species are more likely to invest a greater proportion of energy intake into growth and reproduction resulting in an RA/AS ratio well below 1.0.

System biomass/ total throughput

The total system biomass that is supported by the available energy flow in a system can be expected to increase to a maximum for the most mature stages of a system (Odum, 1971). For the estimation of this ratio, total system throughput is used as a measure consistent with other Ecopath outputs. The system biomass / throughput ratio can take any positive value, and has time as dimension.

Flow to the detritus

For each group, the flow to the detritus consists of what is egested (the non-assimilated food) and those elements of the group, which die of old age, diseases, etc., (i.e., of sources of 'other mortality', expressed by 1 - EE). The flowto the detritus, expressed, e.g., in t·km-2·year-1, should be positive for all groups.

Total system throughput

Total system throughput represents the 'size ofthe entire system in terms of flow' (Ulanowicz,1986). As such, it is an important parameter for comparisons of flow networks. The total system throughput is the sum of all flows in a system, expressed, e.g., in t · km^{-2} ·$year^{-1.}$ It is estimated as the sum of four flow components, i.e.,

Total system throughput=Total consumption+ Total export+

Total respiration+ Total flows to detritus

Connectance index

The connectance index (CI) is for a given food web, the ratio of the number of actual links to the number of possiblelinks. Feeding on detritus (by detritivores) is included in the count, but the opposite links (i.e., detritus 'feeding' onother groups) are disregarded.The number of possible links in an Ecopath model can be estimated as $(N-1)^2$, where N is the number of livinggroups. It has been observed that the actual number of links in a food web is roughly proportional to the number of groupsin the system (Nee, 1990). ThusC I a N ( ) N " H" 1 1 (N " 1 2) which defines a hyperbolic relationship. Odum (1971) expected food chain structure to change from linear toweblike as systems mature. Hence, the connectance index can be expected to be correlated with maturity.

The value of the connectance index is - at least in aquatic systems - largely determined by the level of taxonomicdetail used to represent prey groups, and this preclude meaningful intersystem comparisons.

Mixed trophic impact

Leontief (1951) developed a method to assess the direct and indirect interactions in the economy of the USA, usingwhat has since been called the Leontief matrix. This approach was introduced to ecology by Hannon (1973) andHannon and Joiris (1989). Using this, it becomes possible to assess the effect that changes the biomass of a groupwill have on the biomass of the other groups in a system. Ulanowicz and Puccia (1990) developed a similarapproach, and a routine based on their method has been implemented in the Ecopath system.

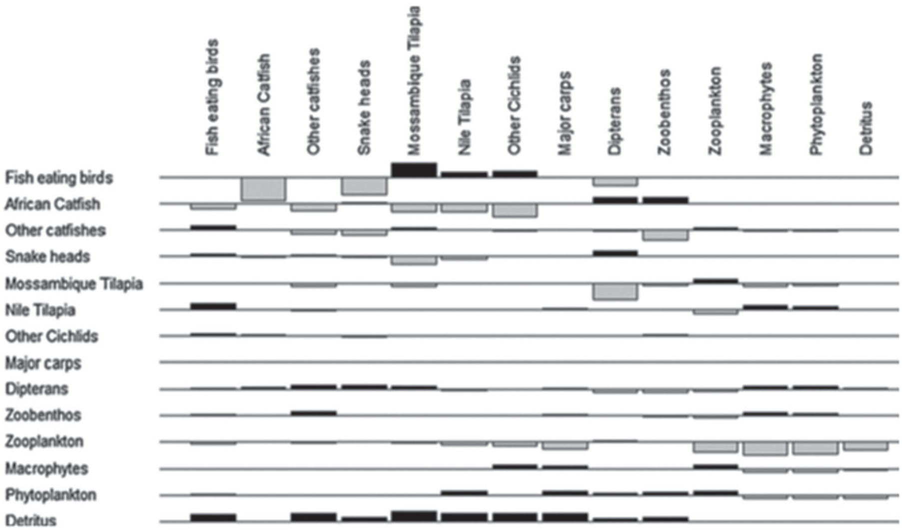

Fig. Mixed trophic impact routine of Kelavarapalli reservoir in Tamilnadu. The black bars shows positive impact and the grey bars show negative impact.

The example given represents the Kelavarapalli reservoir in Krishnagiri District of Tamilnadu (Khan and Panikkar, 2009) |Most groups have a negative impact on themselves, interpreted here as reflecting increased within-group competition for resources. The mixed trophic impact routine can also be regarded as a form of 'ordinary' sensitivity analysis (Majkowski,1982). One should regard the mixed trophic impact routine as a tool for indicating the possible impact of direct and indirect interactions (including competition).

Assessing the ecosystem 'health'

A variety of system indicators are used to assess the health of an ecosystem. Instantaneous snapshots of biomass, flows, and rates of biomass change have sometimes been used to draw inferences about issues such as ecosystem 'health' as measured by mean trophic level or other indices of fishing impact (e.g. Christensen, 1995a; Pauly and Christensen, 1995; Pauly et al., 1998).Ecosystem maturity has been described as a potential descriptor of ecosystem health (Christensen, 1995). Odum (1969, 1971) described how ecosystems develop over time in a non-deterministic way. Implications of this include that in a more mature system all niches should tend to be filled; that a larger part of the energy flows should be through detritus-based food webs; that primary production should be more efficiently utilized; that the total system biomass/energy throughput ratio should be higher; etc. An ecosystem attains maturity after several ecological successions and hence development and maturity of an ecosystem stand in opposition to each other. A mature ecosystem has the capacity to withstand perturbations caused by human beings or nature more than an immature ecosystem.

When ecosystems are disturbed, notably by fishing, we expect their maturity to decrease. This was indicated by the findings of Christensen (1995), who used a series of indicators to rank a large number of ecosystem representations after maturity, and concluded that the ranking obtained was in agreement with the expect state of maturity. Some of the indices for determining the maturity of an ecosystem are as follows.

1) Respiration/ Assimilation ratio can be more than 1

2) Production/ Respiration ratio is always less than 1

3) Primary production/ Respiration ratio is greater than 1 in the early developmental stages of an ecosystem. In mature system, the value is around 1 but in polluted system the ratio is less than1.

4) Primary production/ Biomass ratio is less than 1 in immature system since the biomass accumulates

5) Net system production is the difference between total primary production and total respiration. In immature system, the production is large, but in mature systems, it is close to zero.

6) Connectance index is the ratio of the actual links to the number of possible links in a given food web. Food chain structure changes from linear to web-like as systems mature.

The ecosystem models estimate the carrying capacity of the ecosystems and the biomass at each trophic level by taking into consideration fishery biology aspects. It also helps in quantifying the fishing craft and gears required for optimum harvest from the aquatic system. The models helps to assess the impact of the anthropogenic and also the natural factors such as hydrographic and climatic factors on fish stocks.

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CHAPTER

07

Feed diversity in aquaculture

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Feeds and feeding in aquaculture when viewed from the angle of the diversity of the material in use; both live and dead is interesting. This compilation is an effort to sum up that under the headings, live feeds, wet feeds, dry feeds, formulated feeds and the variety of transformed products in use.

Live feeds

The uniqueness of the aquatic organisms is that their food is available to them in the medium they live. Scarcity occurs only when we culture them restricting their space which we technically refer to as increased stocking density. By imposing the space restriction we not only make the food available to them scarce, but also limit the diversity of the food available to them. Thus, in aquaculture, mainly in the hatchery by imposing the restriction of food diversity we make the food available nutritionally incomplete. Now, we develop techniques and technologies to overcome such deficiencies. The proceeding discussion will first list out the live feeds available to new born and young fish in nature and then move on to an account of live feeds used commercially, their fortification techniques etc.

Even though microbes play an important role in providing nutrition to all aquatic organisms in nature, in hatcheries, they are excluded through several disinfection methods so as to prevent pathogen entry through water. Here, what is forgotten is that almost all B vitamins are synthesized by microbes and becomes available to the animals in nature. In a hatchery when we have to meet all the nutritional requirements, B vitamins have to be supplemented through feeds.

Other live feeds in use are mainly, phytoplankton, zooplankton. Microalgae are the phytoplankton used as the first feed to fish which is less than 10 microns in size. Popularly known as' green water' microalgae has a dual role. They are good water conditioners as well as live feeds. Their nutritional composition varies widely between the marine and freshwater forms. They are also grouped based on fatty acid content as EPA rich and DHA rich. There are some algae which contain only DHA like *Schizochitrium* which is preferred in marine fish larviculture. Products are developed from such algae for commercial scale larviculture applications by blending it with defatted *Haematococcus pluvialis* meal, which is another fresh water green microalgal strain, rich in astaxanthin along with inactive yeast for proteins/carbohydrates (Eg. Algamac, http://www.aquafauna.com/Diets-AlgaMac-Enrich.htm). *Crypthecodinium cohnii* is another unique, heterotrophic, marine dinofl agellate in that DHA is almost exclusively the only PUFA present in its lipid and can be as high as 65% of the total fatty acids used for commercial scale extraction of DHA for nutraceutical applications.

In the case of zooplankton the most preferred are rotifers, artemia nauplii and copepodites. Rotifers, and artemia nauplii and naturally deficient in fatty acids, especially the polyunsaturated fatty acids (PUFA), docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA). Taking note of this, bioenrichment techniques have been used. Feeding both rotifers and artemia nauplii with the DHA rich phytoplankton is the first approach. When the level of enrichment with phytoplankton was found insufficient, oil emulsions were used, albeit problems of handling and contamination. Research and development lead to products easier to handle (Easy DRY Selco and S.presso from INVE) and identification of strains of artemia maintaining enrichment level for more than 24 hours. A strain of artemia from China designated as *Artemia sinica* is found to retain the levels of DHA up to 24 h post-enrichment. As far as rotifers were concerned, size was a constraint in feeding especially some of the marine fish larvae. Discovery of 'small (S) and 'super small' (SS) strains of rotifers from several geographical locations addressed that problem. From India, CMFRI identified *Colurella adriatica* as the small strain of rotifer and up scaled its culture (Madhu et al. 2016) is reported to have a size less than the S and SS strains.

Copepod larval stages known as copepodites with several stages and sizes are known to meet all the nutritional requirements of marine larval fish especially, in nature. With low fecundity compared to rotifers and artemia, maintenance of a steady supply of copepodites in a hatchery is still a challenge. The nutritional completeness in copepodites comes from the presence of phospholipids with PUFA in the ratio of DHA: EPA as 2:1, which otherwise occurs only in the milt and roe of marine fish. That is why, roe phopolipids is chosen as a major natural ingredient in development of live feed enrichment oil emulsions.

Biofloc technology has diffused worldwide ever since it was propounded by Avinimelech (1999). The heterotrophic food web is activated by manipulating the C/N ratio above 10. This is done by adding exogenous carbon sources like flours (tapioca, wheat, molasses etc.) resulting in the shift from an autotrophic system to a heterotrophic system. This results in an increase in microbial protein production due to the formation of biofloc which enhances nutrient utilization by the cultured animal by making available recycled protein which would have otherwise gone waste.

Mechanisms of nitrogen removal from aquaculture systems are (1) dilution (2) plant and algal uptake (3) nitrification by autotrophic bacteria and (4) assimilation by heterotrophic bacteria. Among all the aforementioned techniques and technologies associated in harnessing the potential of biofloc has several clear advantages than disadvantages compared to the other technologies listed. Microbial biodiversity with the involvement of physical, chemical and biological interactions leading to formation of bioflocs and the benefits that accrue in terms of reduction in cost of feeds, biosecurity and health is phenomenal.

Wet feeds

Use of low value fish as feed for cultivation of high value fish has been practiced mainly in Asian region. In a study by Bunlipatanon et al. (2012) it was demonstrated that both the feeding practices Low value fish abbreviated as (Lvf) and compounded pellet feed abbreviated (Cpf) are economically beneficial and environmentally sustainable. The pronounced advantage of Cpf is only in its storability compared to low value fish. Low value fish feeding will naturally indicate high FCR due to the water content in it. Moreover, they need to be prepared to be fed which involves preparatory procedures like degutting. Or, mincing and pelleting using a binder. Surprising the environmentalists advocating

Cpf, it was shown that management with Lvf is more economical than Cpf. Wet feeds in Indian context includes farm made wet pellet, dough ball etc. which has given way to extruded floating pellets in the freshwater aquaculture sector (Ramakrishna et al. 2013).

Dry feeds, formulated feeds and transformed products

All dry feed material and dry formulated feeds made both farm made and factory made come under this category. Evolution of feeds and feeding technology would be worth remembering here. It starts from a no-feeding scenario. Then, fertilization and supplementary feeding started, knowing that both will increase the productivity of the pond. Broadcasting of mash feed from the pond banks and through boats was the next stage of evolution of feeding in aquaculture. This activity gradually changed to feeding doughs, to increase its water stability and made into different shapes knowing the wastage involved in broadcasting dry mash feed. It was the ingenuity of the farmers who started feeding Indian major carps with feed mash in perforated bags which lasts even now as one of the handiest feed dispensing methods. Universal pellet cooker is the first line of technology in commercialization of pellet feed for shrimp. A sinking pellet is essential for crustaceans which are bottom dwelling slow feeders. This was produced using pellet mills with or without cooking. Cooking improved digestibility of feed and now shrimp pellets are mostly steam pelletized with pre-conditioning or post- conditioning.

Extrusion if the state-of-the-art technology in aquatic feed production. This technology came to aquaculture through food industry which borrowed it from plastic and rubber industry. The technology was adopted in aquatic feed production to increase the diversity of the products which can be produced. The product diversity primarily required in aquaculture is to have feed pellets which are fully sinking, slow sinking and floating. Diversity in the size of the feeds range from less than 10 microns to more than 10 mm in diameter. Feeds with the particle size or diameter of 10 microns to 1.5 mm are known as micro feeds. They are used in larviculture nutrition, ornamental fish nutrition and nursery rearing of food fishes. Twin-screw extruders are used to produce such feeds. Feeds used for grow-out culture are called macro feeds which are above 1.5 mm in diameter. Floating and slow sinking feeds of that size are produced using single-screw extruders.

With that account of the feed diversity in aquaculture, let us have a look at what are the feed products available in India. All major international players have their factories here for shrimp feed, because India is the largest aquacultures shrimp producer and exporter now. Recent reports say that Equador will soon over take India in production of farmed shrimp (tom.seaman@undercurrentnews.com Aug. 21, 2018). Extruded fish feed is produced by around 15 feed mills in India. The capacity utilization of these mills is currently below 50% and extruded feeds for carps, catfish and tilapia are available. Indigenously produced marine fish feed is yet to be available commercially, because mariculture of food fish has not reached such volumes. Technologies have been standardized by CMFRI and CIBA. With the increase in farmed fish production in the marine sector this will soon be a reality. With the available overcapacity in extruded fish feed production within the country, the add-on technology to produce marine fish feeds known as vacuum fat infusion technology needs to be brought in to infuse fat content of more than 6% in floating pellets.

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CHAPTER

08

Responsible Fisheries and Biodiversity Conservation

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"By 2020 all fish and invertebrate stocks and aquatic plants are managed and harvested sustainably, legally and applying ecosystem based approaches, so that overfishing is avoided, recovery plans and measures are in place for all depleted species, fisheries have no significant adverse impacts on the threatened species

and vulnerable ecosystems and the impacts of fisheries on stocks, species and ecosystems are within limits" Aichi Biodiversity Target 6.

"Despite many target stocks not yet sustainably managed , fisheries approaches are progressively focusing on a broader range of biodiversity considerations, where as conservation interests are increasingly adopting more socially inclusive approaches"

Friedman et al 2018

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If Biodiversity conservation so far has been a "naming and framing" game; and Fishery conservation is a "give and take" game; Is Responsible fisheries a "hide and seek" game played by both?.

Ramachandran,C

(The lecture-cum-discourse in the winter school will be an elaboration of the question placed above. The following passages are to be treated as a prelude to this discussion. The major reference used for the preparation of this chapter is Garcia et al (2014))

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Biodiversity in our seas is the result of 3.5 billion years of evolution ie, natural selection working on the consequences of genetic variation. The edifice of marine fisheries has been built on this bedrock. But our understanding on the ways in which biodiversity interplays with marine productivity is nascent and expanding. This becomes important when we analyse Biodiversity conservation vis a vis fishery conservation. Before proceeding further let us get familiarized with some of the basic concepts.

Biodiversity is commonly referred to as the combination of species present in an ecosystem. It includes the totality of genes, species, and ecosystems of a region. Each species exhibits genetic diversity also (referred to as metagenome (Ardura et al.2011)). The Convention on Biological Diversity (1992) defines **biodiversity** as the variability among living organisms from all sources, including terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are part.

Diversity is also a measure of the complexity of an ecosystem. As a numerical measure it is a combination of the number of species in an area and their relative abundance. (species richness+abundance or evenness=diversity)..

The system of interactive relationships among organisms (eg. energy transfer) and between organisms and their physical environment (eg. habitat) in a given geographical unit is known as **ecosystem**. It has natural and human subsystems. So it is a socio-ecological system. Species diversity is considered as a major factor behind sustainability as well as stability of an ecosystem.

When we use components of biological diversity in a way and at a rate that doesn't lead to the long term decline of biological diversity it is referred to as **sustainable**. The nature, extent and process of harvesting fish from the marine ecosystem bears significant impact on the long term socio-economic resilience of the fisheries sector.

IUCN (1980) views **conservation** as the management of human use of the biosphere so that it may yield the greatest sustainable benefit to present generations while maintaining its potential to meet the needs and aspirations of future generations. It includes preservation, maintenance, sustainable utilization, restoration and enhancement of the natural environment..

Without integration of environmental concerns, fisheries management becomes meaningless. Thus, it is not difficult to see that responsible fisheries, as a global concern, is a sine qua non of marine biodiversity conservation. But we need to remember that fishing is not the only factor that impact marine biodiversity.

Responsible fisheries as praxis in a locally embedded marine biodiversity scenario is the real challenge for the governance especially in the context of the Aichi target quoted above.

A brief history of Biodiversity conservation and fishery conservation

When you study Biodiversity conservation and fishery conservation through their historical evolution You are likely to have an impression that they are like an estranged couple on the path of a recent reconciliation!.

Biodiversity as a scientific concept is a modern notion. Though the term was coined only in 1988 by E O Wilson in his book with the same title, a normative and culturally transmitted understanding of the significance of biodiversity conservation by the human race played an essential role in our survival as a species.

Traditional societies had to have inherent awareness on the extent to which they could deplete the natural resources upon which they depended for their very survival. It was coupled with a commitment to reduce or eliminate the problem through the "wise use" of the natural resources. In a way , they could identify that "we are the problem". Thus they could conserve certain number of species (including totemic ones) through community control. The case of the Bishnoi community is worth a mention here. The sect founded by Guru Jambheswar (14511536) upholds the value of conservation as a tenet. In 1730, 363 Bishnoi individuals sacrificed their lives to save Khejri trees (It is now the state tree of Rajasthan, Prosopis cineraria and the incident inspired the famous Chipko movement later). Royal decrees protected special areas in India more than 2000 years ago. Emperor

Asoka did establish protected areas of mammals, birds, fish and forests by 252 BC. The Arthasasthra written during 321-300 BC, says that certain forests were protected as Abhyaranyas, considered as forerunners of modern day National parks. It is no wonder that Indian history is replete with such incidents because the Indian way of life had been shaped by Upanishadic teachings like "Ishavasymidam sarvam" which, interestingly, underscored the web of life concept of modern ecology. We would call this as the "holy secret" of conservation movement in India.

But with the emergence of individual property rights and capitalism, the land elsewhere was usurped from the aborigines. The natives were identified as the cause of degradation of natural resources (The "You- We" divide). The conservation of the wilderness by exclusion of the original inhabitants became a norm in post- Industrial colonial countries. Thus came the idea of National Parks especially in the US. They opened the first National Park in 1865 in Yosemite and the second and the most famous Yellowstone Park in 1872. It is heartening to note that about 300 Shoshoni tribe (called 'grass house' people) were killed on a single day in 1863 for making this wilderness preserve.(Garcia et al 2014). In India about 7000 people were proposed to be evicted over a period of five months for the creation of the Lion Protection area in Kuno, Madhya Pradesh (Blaikie and Jeanrenaud,1996). By 2000,around 1650 belonging to the Saharia tribe in the Kuno sanctuary (Saharia meaning companion of tiger) were evicted. The eviction of people for conservation is in fact a global phenomenon. Steven Pinker (2018) calls this as the "dirty secret" of the conservation movement.

Though biodiversity attained scientific stature only in 1988 international attempts for the conservation of nature were already on the anvil much before. A major landmark in global concern for conservation took place in 1956 when International Union for Conservation of Nature and Natural resources (IUCN) replaced International Union for the Protection of Nature (IUPN) which was established in 1948. This reflected a transition from the preservationist approach towards utilitarian aspect of conservation as rational long-term management of natural resources. In 1959 IUCN was asked to enlist and maintain Nature Parks across the world. The Antarctic treaty which gave birth to Conservation of seals (1972) and Convention on conservation of Antarctic Marine living resources (1982) was signed in the same year.

The industrial revolution had a role in fisheries development as well as its decline. Overfishing was "discovered" by John Cleghorn , a wise British fisherman, in 1854 in the context of a collapse of the herring fishery there. The fisheries crisis led to the birth of the fisheries management science in UK and Norway . In fact, Norway took the lead by establishing a commission to investigate fisheries problems through the application of science. Fishery regulations were implemented largely as measures to promote discipline in marketing and fishing operations. Conservation per se was not the objective of these regulations. But what seems as an antithesis the British under the intellectual influence of T H Huxley repealed more than 50 fisheries related acts and brought out a UK Sea fisheries Act which deregulated all fishing activities by 1885. The use of science to resolve the issue of stock fluctuations emerged gradually with the notable works of Huxley, Heinke, Johan Hjort, Baranov, Edward Russel and Ottestad.

The call to use science for the rational exploitation of seafood resources attained a significant institutionalization through the establishment of International Council for the Exploitation of the

Sea (ICES) in 1902. The scientists of ICES took up the issue of overfishing in collaborative mode of enquiry. This is a landmark event as it can be marked as the first attempt of convergence between the two separate streams of biodiversity conservation and fisheries management. In 1913 Australia established the first whale sanctuary. In the same year the world treaty on conservation proposed the formation of the International commission for the protection of wildlife.

Overfishing problem was becoming more vivid by this period. The first world war turned to be the first fishing experiment as the post- war catch rates demonstrated the reality of overfishing. The Leauge of Nations Conference in 1930 passed a resolution to protect various species of marine fauna not only in territorial waters but also out of it. Fisheries scientists had a better grip over the overfishing problem and foundations for the development of the MSY concept were laid by Russel, Graham etc,. The British biologist Michael Graham synthesized the Great law of fishing which said "all fisheries that are unregulated become unprofitable".

The year 1937 saw the first convention on the issue of overfishing namely the London convention for the regulation of Meshes for fishing nets and the size limits for fish (also called as London overfishing convention). (It is worth to remember here that India attained independence only in 1947 and the first marine fisheries research institute (CMFRI) was established in the same year. And only by 2016 an Indian maritime state , Kerala brought out a regulation based on size limits).

By 1945 FAO was established and the first FAO Technical Committee on Fisheries was convened. The committee viewed by catch as a 'waste' issue. The newly independent tropical water countries were just beginning to consider the oceanic resources as a way for economic development. But in the USA salmon was identified as overfished. And Harry Truman , the US president made the famous proclamation claiming sovereignty over the outer continental shelf and the resources therein, arguing their right to make conservation zones there. The second London overfishing conference in 1948 called for mesh size and landing size regulations. They came into effect only in 1954. The conference could not agree the regulation on fishing fleet capacity. The International convention for the regulation of whaling (Washington) adopted MSY as the basis for allocation quotas.

During 1947 -48 we can see international efforts getting mobilized for the protection of living species and habitats for endangered species from human beings. Thus the IUPN was established. The period also saw two significant publications that shaped conservation movements in the US. They are Sand County Almanac by Aldo Leopold (1949) and The Sea around us by Rachel Carlson (1951).

Following the Santiago declaration by Chile, Peru and Ecuador on 200 nautical miles in 1952 the UN proposed to give coastal nations a management authority on the 200 miles contiguous to their territorial waters for protection of ocean resources from extermination in 1953. The next year saw the launching of the industrial trawler called "Fairtry". This opened the era of distant water fishing by factory vessels. It is an irony that the name Fairtry became an oxymoron. The UN-FAO Technical conference on the Conservation of the living resources of the sea was held in 1955. It mooted the idea of regional agreements based on the geographical distribution of the species concerned.

Beverton and Holt published their path-breaking work called "On the Dynamics of Exploited Fish Population" in 1957. The first UN conference on the Law of the Sea (UNCLOS1) was held the next year in Geneva. The first cod war between Iceland and UK happened during this time.

In our case this was the time (1953-4) when Indo Norwegian Project came to Kerala and a new method of fishing called Trawling was introduced marking the phase of "modernization" and the pink gold rush in our fisheries, thanks to the successful export of frozen shrimps to USA by Balakrishnan Nair in Kochi. When the temperate world was grappling with the "boom and bust" issues of overfishing and conservation we were just embarking on the same historical path as a greenhorn.

The early sixties saw the emergence of WWF (1961) and the IUCN Red List (1963). The Red list epitomized a species based conservation logic. The mid -sixties witnessed the pressure built by Environmental NGOs on the high mortality of dolphins caught in purse seining by Tuna fishermen resulting in dolphin safe labels. ICES scientists warned about the inadequacy of mesh size regulations against the problem of overcapacity. The first FAO Committee on fisheries was held in 1966.

The oil tanker Torrey Canyon wrecked in 1967 triggering increased pressure to conserve marine areas. The tragedy of the commons notion was explained by Hardin (1968). Atlantic fisheries introduced catch limitations after finding the impracticability of effort limitations. Early seventies saw UN launching the Man and biosphere programme, FAO estimating the world fisheries potential (100 million tons), the Ramsar convention (recognizing space based approach to conservation), and UN conference on Human environment (Stockholm,1972). USA enacted the Marine Mammal Protection act (which aggravated the Tuna-dolphin conflict) and the Peruvian anchoveta collapsed. FAO recommended a ten year moratorium on whaling. FAO recommended to lower fishing objective from F msy to F 0.1.

The Indian parliament passed the Wild Life protection Act in 1972 (21 August). It is during this period India witnessed the Chipko movement which became a benchmark for socioecological movements in forest conservation. It was in 1972 two Mexican trawlers (24 m) were brought to India for deep sea fishing operations.

A major institution relevant to species conservation namely CITES (Convention on international trade in endangered species of wild fauna and flora) comes into force by 1975. Iceland and UK had the cod war for the third time after Iceland made a unilateral extension of jurisdiction to 200 nautical miles. Australia established the Great Barrier Reef Marine Park, which is considered as a reference in Marine Protected Area. By 1976 US made a major contribution through the US Fisheries Conservation and Magnuson Act, which declared prevention of overfishing and producing optimal fishery yield as a national goal.

In 1977, India declared the 200 nautical miles as the EEZ, much ahead of the adoption of the 1982 UNCLOS.

By 1980s world begin a new discourse on sustainable development along with world conservation strategy by IUCN, WWF and UNEP. The UNCLOS which is an unprecedented effort of codification of the rules relating to all aspects of the use of marine environment by man, gets adopted. The tuna –dolphin issue reach new flashpoints.

The 1980s mark a phase transition in Indian marine fishery sector. Kerala brings in the Marine Fishing Regulation Act (1980) following the national marine fishing regulations of 1978 that was enacted in the wake of the nationwide opposition to trawling . The OBM imported from Japan were demonstrated in

Alappuzha and traditional fishers went for large scale adoption of the technology. The gear conflict between mechanized and non-mechanised fishers became a huge law and order problem. Overfishing was suspected and call for conservation measures came from the unionized fish-workers belonging mainly to the non-trawler sector. The Government engages Babu Paul IAS to conduct a study and the "Report of the committee to study the need for conservation of marine fishery resources during certain seasons of the year and allied matters" is released(1982). Based on the recommendation of a series of committees The Kerala government introduced the ban of trawling during the monsoon season (1988).

During this period (1982-83) in India technology transfer for fishery development gained priority and 110 chartered and joint venture deep sea vessels brought from abroad based at Vishakhapatnam starts operations. But once the operations were limited to 80 m by the government most of these vessels left the country. In Kerala the simmering gear conflict between mechanized fishers and traditional fishers gained a violent momentum which ultimately resulted in the Government declaring annual Monsoon trawling ban through legislation. This is diligently followed by all maritime states for the last two decades.

Kerala took the lead in legislating the MLS requirement for 58 species based on the recommendation of CMFRI (Mohamed et al 2014, GoK 2017). It has also made amendments to the Marine Fishing regulation Act in 2018 and a new set of conservation-oriented regulatory rules are in place now. In a very significant and pioneering move, a three tier Council based participatory governance also has been given legislative muscle by the Kerala government.

Our Marine Biodiversity Context :

Marine Biodiversity as an indicator of the total number of species is still uncertain to the scientific community. Mora et al (2011) estimate that out of the 8.7 million eukaryotic species globally, about 2.2 million are marine. In spite of about 250 years of taxonomic research 91% of marine species await description. The total number of known species of fish is to the tune of 33,000.

(It is interesting to note that we need about 3 lakh taxonomists working for about 1200 years to describe the remaining species on Earth. The whole exercise may cost about US$ 360 billion at an estimated cost of US$48500 per species and the current taxonomic description rate of 6200 species per year!)

The total number of marine fish species on which we have information on the stock status globally is hardly 1000. FAO has a database for 2033 species and 4252 fisheries which yields about 80 million ton per year on average ,caught by an estimated 3.8 million fishers using about 4.6 million vessels catering to the needs of about 3 billion people (FAO2016).

According to Joshi et al (2017) India has identified a total number of 2492 marine species belonging to 941 orders and 240 families so far. In 2017, 788 marine fish species were identified in the landings data. (of which 618 species were landed along the west coast and 592 on east coast.). A total of 16 species have pan India presence. The Fisheries Resource Assessment Division of ICAR-CMFRI has estimated 3.83 million ton of marine fish as the total landing in 2017 (FRAD,CMFRI,2018). The estimated value at landing centre level was Rs 52 431 Crores.

The IUCN Red list of threatened species defines a number of categories of threat based on the risk of extinction in the wild. They are: critically endangered (extremely high risk), endangered (very high risk), vulnerable (high risk), near-threatened (if not managed), least concern (no imminent risk), data deficient (impossible to assess) and not evaluated. The factors that decide vulnerability of a species to extinction are: population demographics, biological characteristics (body size, trophic level, life cycle, breeding structure or social structure requirements for successful reproduction) and vulnerability due to aggregating habits, natural fluctuations in population size (dimensions of time and magnitude) and residency. Vulnerable species are taxa of three types: 1) those likely to move into the endangered category if factors like overexploitation, habitat degradation, and other environmental disturbances continue to operate 2) populations that have been seriously depleted and whose ultimate security has not been assured and 3) populations that are still abundant but are under threat from severe adverse factors throughout their range.

As many as 91 species of endemic marine fishes are known to occur in the coastal waters of India. As of today, about 50 marine fishes known from India fall into the Threatened category as per the IUCN Red List, and about 45 species are Near-Threatened and already on the path to vulnerability. However, only some species (10 elasmobranchs, 10 seahorses and one grouper) are listed in Schedule I of the Wildlife (Protection) Act, 1972 of the Government of India.

It is estimated that an acre of seagrass can support 40,000 fish and 50 million invertebrates.

Biodiversity and eco-system services : the emerging Knowledge gaps

Demonising fishing so as to attribute causative and thus spatial remedial implications consequent to Biodiversity loss is a recent scientific enterprise. The controversial but high impact paper by Worm et al 2006 was interpreted by many a s a (later turned out to be misguided) wake up call . The authors demonstrated through a large body of evidence that biodiversity loss greatly reduces the ecosystem services that we obtain from the oceans, and also contained an analysis projecting ‘‘the global collapse of all taxa currently fished by the mid–21st century.

This projection of global seafood collapse by 2048 resulted in huge media attention and consequent consternation among fishery science community. In an interesting review of citation patterns of the Worm paper, Trevor Branch 2010 concluded that the real intention of the authors was to emphasise biodiversity loss than the 2048 global collapse. But the authors themselves had recognized their limitations in each of their data sources, particularly the inherent problem of inferring causality from correlation in the larger scale studies.

The linkage though strongly speculated is elusive of empirical support. According to Harrison et al (2014)who reviewed 530 studies to analyse the linkage ,could find only limited number of studies that have examined how biodiversity influences timber and fish production, despite the large amount of literature on the impact of best management and/or harvesting practices on wood yield/quality and the impact of fishing on fish attributes.

Tittenser et al (2010) observe that whereas land diversity patterns and their predictors are known for

numerous taxa our understanding of global marine diversity has been more limited, with recent findings revealing some striking contrasts to widely held terrestrial paradigms. After examining data on 11567 species across 13 taxa globally they found maximum diversity among coastal species in western Pacific . Spatial regression analyses revealed sea surface temperature as the only environmental predictor highly related to diversity across all 13 taxa.. Areas of high species richness were disproportionately concentrated in regions with medium or higher human impacts. Their findings indicate a fundamental role of temperature or kinetic energy in structuring cross-taxon marine biodiversity, and indicate that changes in ocean temperature, in conjunction with other human impacts, may ultimately rearrange the global distribution of life in the ocean. The methodological issues like spatial bias in such studies are being highlighted (Gonzales et al 2016)

Brief introduction to Responsible Fisheries

The concept of Responsible Fisheries is synonymous with the FAO Code of Conduct for Responsible Fisheries (CCRF). CCRF is an international instrument for fisheries management which was developed and released by Food And Agriculture Organisation (FAO) functioning under the United Nations on 31 OCTOBER 1995 after a series of international deliberations that began in 1992. More than 160 countries , including India are signatories to this international instrument which is considered as a landmark document symbolizing the international consensus achieved on the necessity for providing guidelines to ensure sustainable utilization of fisheries resources of the world. . The most salient feature of this global instrument is its voluntary nature. The Code is often referred to as the Bible of Fisheries Management.

Why the Code?

The term "Responsible Fisheries' may evoke a doubt whether we have been irresponsible in the way we have been developing or managing our fisheries resources. In fact such a doubt is the stepping stone to understand the concept of Responsible Fisheries.

In common parlance the term "responsibility" is immediately read with the notions of rights or ownership. We tend to have a better sense of responsibility to things we own ourselves. Thus, we feel responsible in taking care of our properties or assets like land or house or vehicle. The lesser the sense of our ownership lesser will be our sense of responsibility. Thus we feel less responsible for the affairs of our ecosystem or political system because we deem them as owned by all. A property belonging to everyone tends to be nobody's property though nobody is excluded from its utilization. This is an important point because in the case of fisheries what we are talking about is a Common Property. Or more correctly an Open access resource. An important question here is "Who actually owns the fish or who actually owns the sea? The de jure owner of the fisheries is the State or the government. That is, fish in our waters is owned by the people. But by all practical sense the fish , once caught by the fisher, becomes his or her property. If so, what about his or her sense of responsibility to ensure its conservation? It may sound a bit puzzling . That is why the Code makes it very clear in the very first article which is given under the general principles of the Code.

" States and users of living aquatic resources should conserve aquatic eco systems. The right to fish carries with it the obligation to do so in a responsible manner so as to ensure effective conservation and management of the living aquatic resources. " (Article 6.1).

What is in principle a property of every one, becomes the property of none in practice. This is the most fundamental challenge in scientific fisheries management. There is a notion that if a sense of ownership is assured, the likelihood of it being taken care of in a responsible manner is more. There are people who argue that it is a misplaced notion. The above-mentioned article of the Code , in fact, is a preemptive answer to this common misunderstanding.

It is for the same reason that , of the more than 230 clauses in the Code classified under 12 articles , a large number vest the responsibility with the State. This ,in a way also, helps to clear the doubts regarding the real meaning of implementing the Code.

Another doubt could be on the real meaning of the voluntary nature of the Code. Being a voluntary instrument the question could be , "Is it something like a "barking dog that seldom bites"?. The code answers this question in its fundamental philosophy called the Precautionary Approach , which is enshrined in Article 7.5.1.

" The absence of adequate scientific information should not be used as a reason for postponing or failing to take conservation and management measures."

In simple words what it means is " Better safe than sorry". It also has a deeper meaning which implies that when a person is given the license or permission or right to fish, what is being transferred is part of the stewardship obligation of the State. One needs to clearly understand this because, when individuals operate in a common property with the sole objective of making profitable livelihoods , the sustainable utilization of such a resource becomes an impossible task in the absence of mutually respected and endorsed regulations. The precautionary principle is further elaborated under the Foundations of the Code below.

Being a global guideline there is much practical sense for keeping it as a voluntary instrument too. Each nation can contextualize the code in sync with its own local realities and requirements at the same time respecting the globally agreed principles and norms. However, there are scholars who argue for making the CCRF a binding instrument given the sorry state of fisheries governance in most parts of the world.

(For details on the concept and praxis of Responsible Fisheries You are requested to refer Ramachandran et al ,2017. Shinoj P and Ramachandran,2018))

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CHAPTER 09

Large Pelagic Resources and Their Fishery in Indian Waters

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These are a group of fishes represented by fast moving pelagics, occurring mainly in deeper waters. They undertake long distance migrations to varying extent depending on species. Along the Indian coasts species of tunas, billfishes, seerfishes, barracudas, dolphinfishes, cobia, queenfishes and rainbow runner represent this resources.

They enjoy wide distribution along the coastal and oceanic waters of mainland and island territories with distribution of adults in deeper waters and young ones of many in relatively shallow waters. Exploratory survey reports and analysis of fishery data suggested resource concentration along waters of Lakshadweep and Andaman Island territories and southern waters of mainland coast.

a. Tunas

They are the major group supporting the LP resource. The resource represented by nine species; five neritic and four oceanic species. Kawakawa (*Euthynnus affinis*), frigate tuna (*Auxis thazard*), bullet tunas (*Auxis rochei*), longtail tuna (*Thunnus tonggol*) and bonito (*Sarda orientalis*t) represent the netritic species. Oceanic species was represented by yellowfin tuna (*Thunnus albacares*), skipjack tuna (*Katsuwonus pelamis),* dogtooth tuna (*Gymnosarda unicolor*) and bigeye tuna (*Thunnus obesus*). They are distributed all along mainland coast and coast of Island territories.

b. Seerfishes

In Indian waters they are represented by four species; Narrow-barred Spanish mackerel (*Scomberomorus commerson),*Indo Pacifickingmackerel (*Scomberomorusguttatus),* Streaked Spanish mackerel *(Scomberomorus lineolatus)* and Wahoo (*Acanthocybium solandri).* Their distribution restricted to mainland coast and supported fishery with major contributions from Kerala, Gujarat, Karnataka, Tamil Nadu and Andhra Pradesh. *S. lineolatus* supported fishery mainly along the southern coast of Tamil Nadu in small quantities.

c. Barracudas

Resource is constituted by thirteen species, including small coastal species; The great barracuda (*Sphyraena barracuda*), *pickhandle barracuda (Sphyraena jello),* sawtooth barracuda *(Sphyraena* ***putnamae),*** *Sphyraena forsteri, Sphyraena obtusata, Sphyraena picuda, Sphyraena acutipinnis*, *S. qenie, S. flavicauda*, *S. chrysotaenia, S. iburiensis* and *S. helleri* and the recently described species Arabian barracuda, *Sphyraena arabiansis.*

They are fished almost all along the coast. Their major abundance is along the southern coast comprising coast of Tamilnadu, Karnataka and Kerala, followed by along coast of Andhra Pradesh and Gujarat.

d. Billfishes

They are represented by five species; three species of marlins and one species each of sailfish and swordfishes. Marlins (Family: Istiophoridae) were represented by three genera; *Makaira, Istiompax and Tetrapturus*. Common in the catches are Black marlin (*Istiompax indica), Indopacific* Blue marlin *Makaira mazara,* and Striped marlin ((*Tetrapturus) Kajikia audax*). Sail fish was represented by *Istiophorus platypterus* and Swordfish (Family Xiphidae) by *Xiphias gladius.* Major share of their catch was landed along the Andhra Pradesh and Kerala coast.

e. Dolphinfishes

Two species; *Coryphaena hippurus* and *Coryphaena equiselis* supported the fishery. They are abundant along the northwest coast, with main fishery along Gujarat coast.

f. Cobia

They are represented by single species, *Rachycentron canadum.* They are abundant along the west coast with large concentration along northwest coast. They are available in appreciable quantity along the waters of Kerala and Karnataka.

g. Queenfishes and Rainbow runner

They are members of the carangid family. Four species represent queenfishes; *Scomberoides commersonianus, S. lysan, S. tala and S.tol* and rainbow runner by one species, *Elagaatis biinnulata* . They are distributed along the entire coast with large abundance along the coast of Andhrapradesh, Orissa and Gujarat.

Fishing methods

Commercial fisheries for large pelagics involves different craft and gear combination. Most fishing units carry different fishing gears and operation of each depends on the resource targeted and ground conditions. Large pelagics form aimed catch in some gears and bye catch in others. Major share of the catch was by hooks and lines and gillnets.

Gillneting: Drift gillnets are generally used to capture LP in the open ocean, consist of a series of individual nets connected together. Because of the high incidental capture of other species, the use of drift gillnets longer than 2.5 km. was banned on the high seas by the United Nations. Only a small percentage of the world catch of tunas is taken with gillnets.

Longlining: Longlines are passive and non-selective to the extent that it can capture several species of LP resources along with pelagic sharks. The gear fishes mostly below 100 m depth, where temperatures are cool and the largest of many species frequented.

Purse-seining: Purse seines target mostly shoaling resources especially tunas.

Pole and lining: Pole-and-line fishing is a two-mode type of fishing targeting mainly skipjack and yellowfin tunas. The live bait was used to attract the tuna to the vessel where they were caught by pole-and-line gear. If good aggregation of tunas attracted towards the live bait, large volumes could be captured in a short time. Pole-and-line fishing was at one time the major type of tuna fishing in Lakshadweep.

Trolling: Trolling consists of towing several lines with bait or lures attached from vessels, generally less than 20 meters in length. Most troll fisheries target large yellowfins and narrow barred Spanish mackerel, but several other species are also taken. Trolling accounts for only a very small percentage of the total LP catch.

Fish Aggregating Devices (FADs): Fish Aggregating Devices are structures located at surface or at mid-water depths to take advantage of attraction of pelagic fish to floating objects. FADs anchored in depths beyond 500 m are generally more successful in attracting schools of skipjack *(Katsuwonus pelamis),* yellowfin (Thunnus *albacares)* and bigeye *(T. obesus)* tunas. Smaller tunas (skipjack and immature yellowfin) at the surface and larger tunas (mature yellowfin and bigeye) at depths of 300-400 m. FAD's are deployed in Lakshadweep waters to support pole and line fishing

Catch and trend

Catch of all LP resources together constituted 206,207 t annually, which accounts nearly accounting 5.48 % of the total marine fish landings along the mainland during 2012-16. Their catch during the period varied between 194348 and 231,362 ton. Major share, over 50% of the catch was by tunas (88,417t) followed by seerfishes (51,811t), barracudas (29,782 t) and queenfishes and leather jackets (15925 t). Other resources contributing to the fishery are biillfishes-10,822 t, dolphinfishes-7,517 t and cobias-3,060 t. LP fishery of Lakshadweep and Andaman regions were supported mainly by tunas. It was respectively14,428 and 2,531 ton from the Island territory.

Over the years, the LP landing has steadily increased. It was 62,000 t in 1985, 1,98,991 t in 2012, 2,10,154 t in 2015 and. 231,362 t in 2016. The trend in production indicated that, LP fishery as such is in a developing state and there is scope for increasing production from Andaman and Lakshadweep waters and from distant waters within the Indian EEZ.

Landing by sector/gear

Mechanised and motorised sector together represent the LP fishery of the country, with only negligible contribution from artisanal sector. Major share of the landings was by mechanised sector (60.5%) and the rest by motorised sector. Large pelagics were caught both as targeted and incidental catch in several gears. Major share of the landings was realized in gillnets (39.6%), trawls (24.3%), purseseines (13.4%) and hooks and line (7.7%). Considerable variation was also observed in the catch composition by different gears as they operate in specific areas.

CHAPTER 10

Biology of Some Important Demersal Fishery Resources

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ICAR-Central Marine Fisheries Research Institute

Global total capture fishery production in 2014 was 93.4 million tonnes, of which 81.5 million tonnes from marine waters and 11.9 million tonnes from inland waters. Total capture production in marine waters was 81.5 million tonnes in 2014, a slight increase on the previous two years (SOFIA, 2016). The marine fish landings from the coast of the main land of India in 2017 was estimated as 3.83 million tonnes (t) showing an increase of 5.6% compared to in 2016. Landings in all the maritime states except Tamil Nadu increased in 2017. Highest landings was along the Gujarat coast (7.86 lakh t; 20.5%), followed by Tamil Nadu, Kerala and Karnataka with 6.55 lakh t (17.1%), 5.85 lakh t (15.3%) and 5.48 lakh t (14.3%). Percentage increase was high in Goa (64%), West Bengal (33%), Maharashtra (30%) and Kerala (12%). Along the Indian coast demersal finfishes form one of the major components in the marine fish landings. Demersal fish groups such as the sharks. groupers. snappers. threadfins, pormfrets and Indian halibut are commercially valuable and contribute substantially to the economy of Indian marine fisheries. Some of these groups, especially of large-size, are targeted by the fishermen by using different craft and gear combinations. However, several other demersal finfishes are not targeted, but are landed as bycatch by shrimp trawlers.

GROUPERS : This group is abundant in the rocky grounds off the South west coast and south east coast of India and is exploited by, hooks and lines, traps and gill nets. All India landings of perches is 4.27 lakh tonnes. Around 42 species of groupers have been reported from different parts of India. Family Serranidae includes *Epinephelus malabaricus* (Malabar grouper), *E.tauvina* (Greasy grouper), *E.bleekeri* (Dusky-tail grouper),*E.areolatus* (Areolate grouper),*E .diacanthus* (Spring cheek grouper/ six-bandedreef cod), *E.epistictus* (Broken-line grouper), *E.fasciatus* (Red banded grouper),*E.flavocaeruleus* (Blue and yellow reef cod), *E.latifasciatus* (Banded grouper),*E.morrhua* (Banded cheek reef cod), *E.undulosus* (Brown- lined reef cod), *E.merra* (Wire netting reef cod), *E.fuscoguttatus* (Brown marbled grouper), *E.chlorostigma* (Brown spotted grouper), *Cephalopholis sonnerati* (Red coral cod) and *C.boenack* (Blue-lined seabass).

Groupers have long lifespans, are slow growing, relatively large in size, and have a low natural mortality rate. The larger species form breeding aggregations, and most species are protogynous hermaphrodites. Among the Epinephelinae, monandry protogynous hermaphroditism is the most common sexual pattern [Shapiro, 1987]. A few species, such as the *Epinephelus coioides* and the *Epinephelus andersoni*, are diandry, where the males can either develop from the females or they can develop directly from the juvenile phase [Sadovy and Shapiro, 1987; Fennessy and Sadovy, 2002]. The latter sexual pattern suggests that some females do not change sex at all, and some males do not pass through female stages at all. Their aggressive nature and relatively large size makes them more vulnerable to fishing gears (Munro andWilliams, 1985). They are generally long-lived and slow growing with low rates of natural mortality (Ferreira and Russ, 1994; Grandcourt, 2005), form spawning aggregations (Domeier and Colin, 1997) and this predisposes them to overexploitation. Furthermore, aspects of their reproductive biology, such as female biased sex ratios and the potential for the differential removal of larger older males make them particularly vulnerable to the effects of fishing (Sadovy, 1996). Protogynous species are said to be far more vulnerable to fishing pressure than comparable gonochoristic stocks (Huntsman and Schaaf, 1994). For protogynous species, in which males tend to be larger than females on average, size-selective fishing mortality (gillnetting/hooks is used for fishing) may result in the loss of larger older males (as reported by Sadovy, 1996), which may result in the possibility that insufficient males remain in the reproductive population to fertilize eggs from all females (Koenig et al., 1993). Marine protected areas (or no-take zones) are considered a valuable management alternative for protecting the size and age structures as well as the breeding populations of coral reef fishes.

Epinephelus coioides is found along the coastlines of continents and large islands to a depth of 100m where it inhabits coastal reefs and is often found in brackish water in association with mud and rubble substrates (Lieske and Myers, 1994). Juveniles are common in the shallow waters of estuaries, over sand, mud and gravel and among mangroves (Kailola et al., 1993; Sheaves, 1995). The diet consists of fishes, shrimps, crabs and other benthic crustaceans. It is a large, relatively long-lived species attaining 111.0 cm total length and 15.0 kg in total weight with a maximum age of 22 years (Mathews and Samuel, 1991; Heemstra, 1995). As with many of the Epinepheline groupers, *E. coioides* is a protogynous hermaphrodite, undergoing female to male sex change (Quinitio et al., 1997).

Epinephelus areolatus :The areolate grouper *Epinephelus areolatus* is a coral reef fish that is widespread in the Indo-Pacific region but has been recorded nearly worldwide, including in the Red Sea, Persian Gulf, South Africa, Japan, the Arafura Sea (Russell and Houston, 1989). In the Arabian Gulf it reportedly has a prolonged spawning season that extends from June to September for females and to August for males. *E. areolatus* reached sexual maturity at 24.3 cm for males and 25.5 cm for females, which correspond to 2.04 years and 2.23 years, respectively. Fishing of spawning aggregations leads to a reduction in the average size of the individuals caught and a remarkable decline in the M:F sex ratio since this is a protogynous species.

E. diacanthus: The ovary is of the cyst -ovarian type into which matured eggs will be released during ovulation; the ova will pass through oviduct on their way to go out at the genital pore. The genital pore is a smaller pore behind the anus; which becomes pinkish during spawning season. The wall of the gonad is covered externally with a peritoneal layer.

Stages of the ovary

Stage I –immature I - relatively small, translucent and white pinkish in colour.

Stage II - Mature resting female / maturing female stage II of larger than Stage I and white brownish in colour.

Stage III - is defined as the ovarian stage in which active vitellogenesis taking place in preparation for spawning in the mature active female/ripe female. The ovary occupies 2/3rd of the body cavity and is light yellowish in colour..

Stage IV –Ovary occupies the gonad cavity –is pinkish in colour and is ready for spawning. Gonad weight is also increased.

Stage V –Spent –Gonads are flaccid –loose and shrunken –covered with blood shots and veins

Species in Indian waters

Some common species

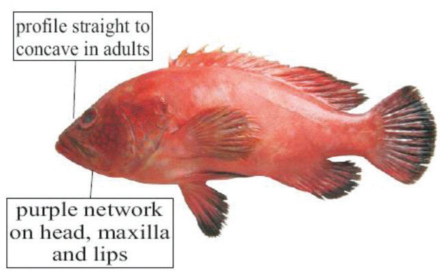
Aethaloperca rogaa **(Forsskal, 1775)**

Redmouth grouper

D IX, 17; A III, 8; P 17-18; V I, 5.
Body rounded its depth greater than head length; mouth slightly superior; dorsal profile of head steeply sloped; small hump on nape; pre-operculum finely serrated; operculum with 3 undeveloped spines; pelvic fins equal to pectorals, reaching the level of anus or beyond; caudal fin truncate.
Body uniformly dark brown to black; reddish inside the mouth, gill cavity and upper jaw membrane; soft-rayed part of dorsal fin and caudal fin margin white white.

Cephalopholis sonnerati **(Valenciennes, 1828)**

Tomato hind

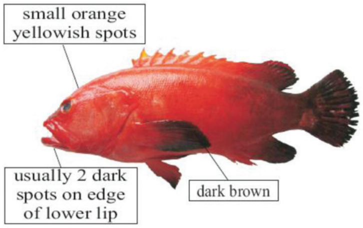


D IX, 15; A III, 9; P 17-18; V I, 5; Gr 14 to 16.

Body depth, greater than or equal to head length; dorsal profile of head near eye and nape strongly convex; mouth small, slightly superior; maxilla reaches posterior of eye; pre-operculum rounded; **operculum spines very small, poorly developed**; Body bright orange to red, with scattered bluish-white spots; head purplish to red with numerous close-set orange-red spots; opercular flaps dark reddish; all fins reddish, the membranes of soft dorsal, caudal, anal, pectoral and pelvic fins dark red to dusky.

Cephalopholis urodeta

Similar to *C. sonnerati*, but differs in the absence of the reticulate pattern in *C. sonnerati*

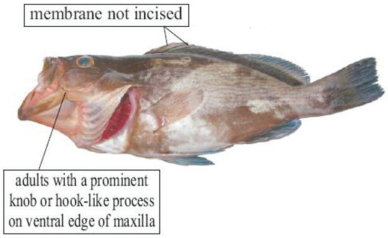


***Epinephelus polyphekadion* (Bleeker 1849)**

Camouflage grouper
D XI, 15; A III, 8; P 16; V I, 5; LL 47 to 52; Gr (8-10) + (15-17).
Dorsal profile of head evenly convex; maxilla reaches rear edge of eye; pre operculum rounded, the serrae at corner slightly enlarged; two undeveloped spines in operculum; inter spinous membranes moderately incised; caudal fin rounded; body scales ctenoid.
Body pale brownish covered with numerous small dark brown spots; some irregular dark blotches superimposed with the spots scattered in head and body; **a prominent black blotch on caudal peduncle**; dark spots extend all over head, including lower jaw, lips and inside of mouth; numerous small white spots on fins and a few on head and body.

***Epinephelus undulosus* (Quoy & Gaimard 1824)**

Wavy-lined grouper
D XI, 20; A III, 8; P 18; V I, 5; LL 70 to 75.
Eyes small; mouth superior to slightly protractile; pre-operculum highly serrated at the angle; operculum notched with 2 undeveloped spines; **dorsal fin membrane not notched** between the spines; body scales ctenoid, except on belly; caudal fin truncate to slightly concave. Body generally brownish to purplish grey, usually with golden brown to yellowish spots on head and upper body, which becomes wavy longitudinal lines in mid body; median fins and pelvic fin black to brown in base and bluish in the tip; preserved specimen becomes brownish with dark spots and lines.

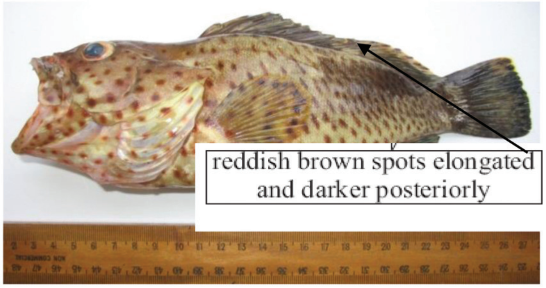


***Epinephelus longispinis* (Kner 1864)**

Longspine grouper

D XI, 16; A III, 8; P 18; V I, 5; LL 49 to 53; Gr (8 to 11) + (15 to 17).

Body deep, upper edge of operculum straight or slightly convex, with 3 undeveloped spines; the third or fourth spine longest, its length contained 2.1 to 2.6 times in head length; caudal fin rounded, convex.



Body pale to brownish and grey laterally; reddish to dark brown spots all over the body, which is round in head and slightly elongated in sides; some dark spots or blotches at dorsal fin base; median and paired fins with dark brown spots; tip of the fins slightly yellowish; preserved specimen becomes brownish with dark spots.

***Plectropomus leopardus* (Lacepede 1802)**

Leopard coral grouper

D VII, 12; A III, 8; P 16; V I, 5; LL 89 to 99; Gr (1-3) + (6-10).

Body elongate, robust; Head comparatively small, 2.7 to 3.1 times in standard length; dorsal profile of the head slightly slopped, with a concave insertion near nape; eyes slightly prominent; mouth oblique, slightly superior; preoperculum rounded, with 3 large, spines along lower half; operculum with 3 flat spines, the upper and lower spines covered by skin; pectoral fins subequal to pelvic fins; caudal peduncle broad; caudal fin emarginated.

Body brownish to orange-red, with numerous small dark-edged, blue spots on head and body (except ventrally) and fins; spots slightly elongated near mid body; pectoral fins reddish with darker rays; a indistinct dark band at rear margin of caudal fin.

***Variola albimarginata* (Baissac 1953)**

White-edged lyretail

D IX, 14; A III, 8; P 18; V I, 5; LL 120-130; Gr (7-9) + (13-16).

Body elongated, moderately deep; dorsal profile of head gently sloped; eyes small; mouth oblique, terminal; jaws with sharp canine teeth; maxilla reaches beyond the eye; pre-operculum finely serrate; operculum spines not well developed; soft rays tips of fins slightly elongated; caudal fin crescentic, the upper and lower rays elongate.

Brownish orange to reddish with numerous irregular, small whitish to pink or lavender spots to streaks; fins colour same as body except pectoral fin and caudal fin rear margin; rear margin of caudal fin dusky with a narrow white edge; pectorals yellowish; preserved specimens changes complete brownish white.

***Epinephelus coeruleopunctatus* (Bloch, 1790)**

White Spotted grouper

D XI, 15; A III, 8; P 18; V I, 5; LL 52-62; Gr 10+14-17.

Body moderately elongated; dorsal profile of the head nearly straight; head pointed; Body depth more or less equal to head length; pre-operculum rounded, serrated; eyes big, prominent; dorsal and anal fin soft rays, pectoral and caudal fins rounded.

Body brownish gray to black with numerous large white spots including fins; dark blotches below dorsal fin and caudal peduncle; prominent black streak on maxillary groove.

***Cephalophalis miniata* (Forsskål, 1775)**

Coral hind

D XI, 14; A III, 8; P 17; V I, 5; LL 47-56; Gr 7-9+14-16.

Body moderately deep; dorsal profile of the head straight, with convex above eye; maxilla big, crossing the rear edge of eye; eyes small; pre-operculum rounded; soft rays of dorsal and anal fin, pectoral and caudal fins rounded.

Body orange to reddish brown, with small blue spots all over the body including fins; Margin of soft rays of dorsal and anal and caudal fins bluish.

Anyperodon leucogrammicus **(Valenciennes, 1828)**

Slender grouper

D XI, 14; A III, 8; P 15; V I, 5; LL 61-72; Gr 7-9+14-17.

Body elongated, slightly compressed; head elongated, its length greater than body depth; dorsal profile of the head slightly slopped to straight; eyes moderate; mouth

large terminal; pre-operculum slightly serrated, rounded; interfin membrane of soft rays transparent; soft rays of dorsal and anal fin, pectoral and caudal fins rounded. Body greenish brown to gray with numerous reddish spots including head and fins; spots in head small; 3 to 4 longitudinal white bands running from mouth to caudal peduncle.

Cephalopholis argus **(Schneider, 1801)**

Peacock hind

D XI, 16; A III, 9; P 16; V I, 5; LL 46-51; Gr 9-11+17-19.

Body deep; head big, its length 2.4 to 2.7 times in standard length; eyes small; mouth big, terminal to slightly superior; maxilla extends beyond to the level of eye; pectoral fin fleshy; dorsal and anal fin soft rays, pectoral and caudal fins rounded.

Body dark brown with numerous blue to white spots with dark margin; 5 to 6 pale vertical bars on the rear part of body; dorsal fin spines with orange margin; posterior margin of median fins darker with a narrow white tip; pectoral fin with dark brownish to purplish red posterior edge.

Cephalopholis formosa **(Shaw, 1812)**

Bluelined Hind

D IX, 18; A III, 8; P 15; V I, 5; LL 47-51; Gr 6+15.

Body moderately, deep; dorsal profile of the head slopped with convex inter-orbital; eyes small; maxilla ends at

posterior end of the eye; dorsal and anal fin soft rays, pectoral and caudal fins rounded; body scales ctenoid.
Body dark yellowish brown, fins darker; wavy longitudinal blue lines all over body including head and fins; blue spots on the snout, lower part of head and thorax.

Epinephelus lanceolatus **(Bloch 1790)**
Giant grouper

D XI, 14; A III, 8; P 16; V I, 5; LL 46-51; Gr (9-11)+(17-19).
Body robust in adult and slightly deep in juveniles; dorsal profile of the head slightly convex; eyes small; mouth moderately big, terminal to superior; maxilla reaching rear edge of eye; pre-operculum finely serrated in edges; inter fin membrane of spines notched; soft rays of dorsal and anal fin, pectoral and caudal fins rounded.

Body greyish yellow above, grayish white below and sides with numerous uneven black blotches all over the body; head darker; fins yellowish with black blotches; juveniles with 3 irregular black bars in body, large adults dark brown to grey. This is a protected species under Wild Life (Protection) act, 1972 of India.

Cephalopholis cyanostigma **(Valenciennes, 1828)**
Blue spotted hind

D IX, 15; A III, 8; P 15; V I, 5; LL 46 to 50; Gr 7-9+14-18
Body moderately compressed, deep; dorsal profile of head convex above eye; eyes small slightly projected; mouth large terminal to superior; maxilla vertically reaching the rear edge of the eye; pre-operculum rounded; body scales ctenoid; soft rays of the dorsal and anal fin, pectoral and caudal fin rounded.

Body brown to brownish red, head darker; with numerous black edged bluish spots all over the body including fins; spots in head, chest and belly comparatively big with spots in fins and posterior body; sides with 4 to 5 dark chain like bars; median fins darker than body colour; pectoral fin darker or with black margin at the free tip.

Epinephelus ongus **(Bloch, 1790)**

White streaked grouper

D XI, 14; A III, 8; P 15; V I, 5; LL 48 to 53; Gr 8-10+15-18.

Body comparatively deep; dorsal profile of head steeply sloped, slightly convex above eye; eyes big projected; mouth moderately small; maxilla vertically reaching middle of the eye; head slightly pointed; pre operculum rounded; soft rays of dorsal and anal fins, pectoral and caudal fin rounded.

Body brownish with numerous small white spots all over the body which sometimes forms wavy lines; head darker with less white spots; median fins with small white spots, posterior margin darker with white tip; paired fins greyish brown.

Epinephelus merra **(Bloch, 1793)**

Honeycomb grouper

D XI, 17; A III, 8; P 17; V I, 5.

Body robust, slightly compressed, elongated; mouth superior, large, maxilla exposed, slightly protractile; small, slender teeth on jaws, vomer and palatine; some small canines on front; eyes prominent; dorsal profile of the head sloped; pre-operculum serrated; one flat spine on operculum; small ctenoid scales; pectoral fin like an hand fan; caudal fin rounded.

Body grey above and lighter below; brown to black spots all over the body, hexagonal anteriorly, rounded posterior; fins rays of dorsal and caudal fin yellowish; pectoral and pelvic fins dark brown to black.

Epinephelus flavocaeruleus **(Lacepède, 1802)**

Blue-and-yellow grouper

D XI, 8; A III, 5; P 16; V I, 5; LL 61-74; GR (9-10) + (15-17)

Body deep; dorsal profile convex; eyes small, head length 2.5 in SL; BD 2.5 in SL; nostril top of the eye; mouth inferior;

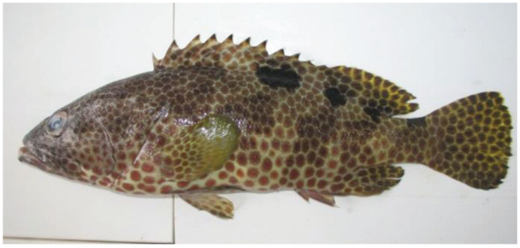
teeth canine; operculum with undeveloped spines; pre-operculum serrated; interfin membrane of dorsal fin deeply notched; caudal fin truncate; caudal peduncle thick and short. In fresh condition body colour blackish with bright yellow dorsal, anal and caudal fins; outer tip of caudal blackish; in formalin preserved specimens fins are whitish; black tip of caudal fin is retained.

Epinephelus spilotoceps **(Schultz, 1953)**

Four saddle grouper

D XI,17;A III,8;P 17;I,5;LL 60-69;GR (7-8)+(15-18)

Body elongated; pre dorsal profile is slightly convex; eyes small; head length 2.5 in SL; BD 2.5 in SL; mouth inferior; maxillary ends at the middle of the eye; teeth canine;



operculum with one developed pine; pre-operculum serrated; pectoral fin origin in front of the pelvic fins; dorsal fin spinous interfin membrane deeply notched; caudal fin truncate; caudal peduncle thick and short. In fresh condition the body colour is yellowish brown with spot all over the body; in formalin preserved specimens the black spots are light black.

Epinephelus diacanthus **(Valenciennes, 1828)**

Thornycheek grouper

D XI, 15-17; A III, 8-9; P 18-20; VI, 5; Ll 105-120.

Body depth contained 2.8 to 3.2 times in standard length. Pre-opercle border forming nearly a right angle, with 1 to 3 enlarged serrae at the angle; sides of lower jaw with 2 rows of small subequal teeth; anterior nostrils tubular, with a large flap posteriorly extending over rear nostril; lower gillrakers 14 to 16. caudal fin rounded to almost truncate. Pored lateral line scales 53 to 60. Body generally buff, with 5 more or less distinct, vertical dark bars;

4 bars below dorsal fin and 5th on caudal peduncle. Ventral part of head and body reddish. Some specimens with a black streak across cheek at upper edge of maxilla. Dark bars on body sometimes absent.

***Epinephelus malabaricus* (Schneider, 1801)**

Malabar grouper

D XI, 14-16; A III, 8; P 18-20; VI, 5; Ll 98-114.

Body depth contained 3.0 to 3.6 times in standard length. Pre-opercle finely serrate, with a shallow notch, the serrae enlarged at the angle; rear nostrils not more than

twice the size of anterior nostrils; lower gillrakers 13 to 16; mid lateral part of lower jaw with 2 rows of teeth. Midlateral body scales distinctly ctenoid with minute auxiliary scales.

Head and body generally pale greyish brown covered with small orange, golden brown, or dark brown spots. Five more or less distinct, slightly oblique, irregular, broad, dark bars on body; these bars are darker dorsally and the last 3 are usually bifurcate ventrally; the first 4 bars usually continued onto the dorsal fin, the last bar covers most of the caudal peduncle; usually 3 dark blotches on interopercle, the first 2 sometimes merging to one blotch; small, irregularly shaped and spaced, white spots visible on head and body of some fish; soft dorsal, caudal, anal and pectoral fins brownish-black with small dark spots on basal half of fins.

Reproductive Biology Stages:

Threadlike : Sex cannot be determined at this maturity stage, and the gonads in individuals appear as filaments occupying a small portion of the body cavity

Stage I (Immature or inactive): The gonads have a translucent appearance, and testes are smaller and thinner than ovaries.

Stage II (Spent recovery with colour): The gonads are translucent and enlarged. The testes do not contain sperm, while the ovaries possess a few small eggs.

Stage III (Developing): Gonads are larger, and testes are opaque without sperm. Ovaries are translucent with small eggs. Extend upto ¾ of gut

Stage IV (Ripe or Fully developed): Testes are white, sperm is expelled from the core when cut. Ovaries are not translucent but opaque and solid with fully formed eggs.

Stage V (Spawning): Gonads are enlarged, and occupy most of the body cavity. Milt and eggs are expelled from the genital openings on application of slight pressure to the two sides of the genital tract.

Stage VI (Spent): Ovaries are flaccid with few degenerating eggs in the ovary, while the testes are almost empty.

Gonado somatic index –GSI -.

Gonadosomatic indexes (GSI) were calculated as GSI=(GW/(TW-GW))x100, where GW= gonad weight (g) and TW=total fish weight (g). The state of maturity of a fish may be determined by the size of ovaries. Gonado-somatic index (GSI) indicates the stage and readiness of the ovary for maturation and spawning. Throughout maturation, the GSI values of females were much higher than males implying a greater proportion in body reserves were allocated to the gonads Gonadosomatic index has been used by many earlier investigators like Htun-Han (1978) to explain the degree of ripeness of ovary in a number of fishes.

Hepatosomatic indexes (HIS) were calculated as HIS=(LW/TW)x100, where LW= liver weight (g) and TW= total fish weight (g).

The condition factor (K) is a measure of fish energy reserves. Condition factor values follow interannual

variations and seasonal cycles (Lambert and Dutil, 1997) Fulton's condition factor is calculated using the equation: KF = 100×(W/L3)

The **length-weight relationship** calculated using the expression: $W = aL^b$

where, W is the body weight (g) and L is the total length (cm).

Parameters a and b can be estimated by linear regression analysis based on natural logarithms:

$\ln(W) = \ln(a)+b \ln(L)$

Additionally, 95% confidence limits of b and the coefficient of determination r^2 were estimated. In order to confirm whether b values obtained in the linear regressions were significantly different from the isometric value (b = 3), a t-test can be applied,

Fecundity – The number of eggs produced per female per unit time (e.g., per spawning season). Fecundity has been considered as the number of ripening eggs in the female prior to spawning. Fecundity of the fish is the most important aspects of the reproductive biology of the fish which must be understood to explain the variation in the level of production as well as to make efforts to increase the amount of harvest. Alternatively fecundity may be expressed per unit body weight of post stripes fish when it is known as relative fecundity because the number of eggs produced for each unit increase in weight shows significant linear variation

Fecundity is calculated by the following formula: F = n×G/ g

where, F is fecundity, n is the average number of eggs in sub-sample, G is weight of the gonads and g is the weight of the sub-sample.

CHAPTER

11

Age determination in fishes and validation using fish using hard parts

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Fisheries management relies on understanding the fish population dynamics while determining the biological parameters, including size at maturity, duration of spawning season, mortality estimates, age and growth, Accurate information on age of fish is an important pre-requisite for extracting precise information on growth, mortality, recruitment and other fundamental population parameters of fishes for stock assessment. The outcome of conventional age estimates using length frequency data depends upon the sample quality, selectivity of the fishing gear etc. The stock assessment results may therefore be affected and sometimes give results which is having no bearing on reality. The hard parts of the fishes also grow with the fish and the growth process may left some inscription on such parts and if that can be interpreted properly, will get precise idea on growth. These inscriptions may result from either changes in the environment which the fish inhabits, or food availability, or physiological states of the fish. However, free swimming fishes always lives in ideal conditions and do not leave any environment related markings in their skeletal structures. So interpretation of hard part inscriptions need utmost care.

Ageing techniques

Several methods were wmployed to

Direct observation

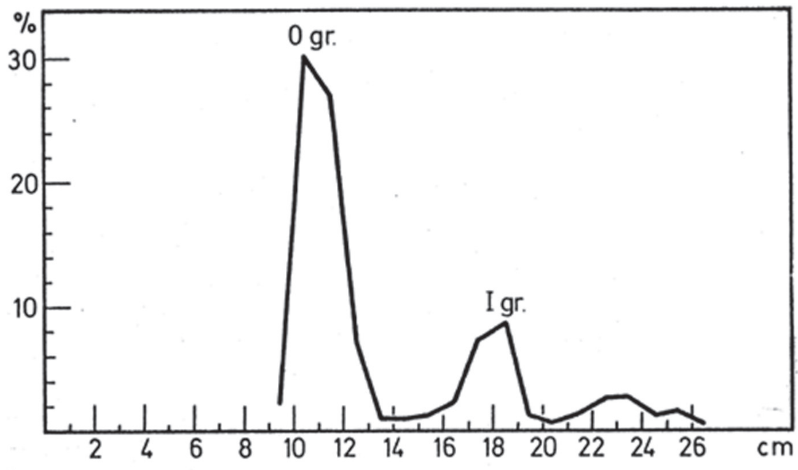
This is the simple method, where age and growth is monitored directly fattening them under confinement or physical/chemical tagging and releasing of fishes of known age to wild and monitoring their growth against time when captured. The data so generated were used to interpret the age of wild caught fishes. Fattening in confinement is the oldest technique described initially by the fish culturists. Tagging and marking experiments are conducted as the data collected are useful in estimating the population size, mortality rates and migration. Tagging does not enable individual fish to be aged unless the age of the fish at tagging is known. The method is very useful for fish living in areas where the growth is continuous throughout the year. It is useful when large numbers of fish recaptured at annual intervals are available. However, cultivated or tagged fish seldom have the same growth rate as that of the wild or untagged fish. Tagging or marking of fish usually involves considerable time and recapturing is not assured.

Analysis of progression of modes in the length frequency data

Length frequency data are used in various analytical, graphical and software assisted techniques to estimate the age, growth and other population parameters The common methods employed are**;**

a. Petersen method:

This is a single sample method and is very simple, fastest but most inaccurate method of ageing fishes. This method can be used only with species which have a restricted spawning season so that the fish bred in a single season can be identified as a single mode in a polymodal length distribution. The mode with the lowest value is identified as O-year group fish. Subsequent modes will be 1-year group, 2-year group fish and so on. The method can be very good for young fish but becomes increasingly less useful for older fish as the growth rate slows down and the modes merge.



In practice length-frequency distributions of fish caught over the shortest time period possible are plotted; the shorter the time period the more precisely the modes will be defined. A regular sequence of such length frequency distributions enables the progression of the modes to be followed.

b. Monthly modal progression analysis

Length frequency data collected at random from the commercial and experimental fishing are used to estimate the age of the age and growth of the fish.

c. Scatter diagram technique of monthly modal length

By plotting the monthly modal values of the length frequency data of fish as a scatter diagram, growth as well as the number of broods recruiting per year can be estimated.

d. Bhattacharya method

This is a graphical method of splitting a composite distribution into separate normal distributions, i.e. when several age groups or cohorts of fish are represented in the same sample. (For details consult FAO Fisheries Technical Paper No. 306.1 ,Rev.).

e. Probability paper/plot method

The aims to resolve the normally distributed components of a length frequency distribution.

Age determination using hard parts of fish

Basic principle: Fishes grow continuously, but growth rate varies over time and season. All calcareous structures in the body also grow in the similar pattern. Any changes in growth rates may be reflected as some pattern of structural discontinuities or as zones or bands in the hard parts based on the rate of mineral deposition. By tracking down these discontinuities termed as 'rings' age of the fishes can be determined if allot some time-scale to thee patterns.

Hard parts

All hard parts are not suitable for age determination. Hard parts on which distinct growth inscriptions available includes scales, otoliths, opercular bones, spines, vertebrae etc. Among skeletal structures, otoliths and scales are most widely used as they are easy to collect and store.

Otoliths

Otoliths are three-dimensional structures but do not necessarily grow at the same rate equally in all dimensions. If there is a pattern in the otolith it will be composed of a number of concentric shells with different radii. Depending on the amount of organic material in each shell or zone, its appearance will vary from extremely opaque to hyaline.

There are three pairs of otoliths in teleost fishes. Among these, Sagittal otolths are generally used for age determination as they are the largest and easy to collect and process.

Scales

Scales vary in shape depending on the species. Scales are almost two-dimensional structures. The anterior part is formed of a series of sclerites which should extend in a regular pattern from the centre of the scale. The structural discontinuities used for age determination result from irregularities in the pattern of the sclerites and are usually called as 'rings'. Scales are thin structures they need no preparation before viewing.

Validation

Age and growth estimates obtained from hard-parts may be cross checked with estimates from conventional methods for validation for correctness and improvement.

In all cases, detailed information on the biology and population dynamics of the fishes under study is an essential pre-requisite for ageing work.

CHAPTER 12

Cryopreservation of Fish Milt: A Useful Tool for Conservation of Fishes

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Introduction

The increasing demand for fish resulted a decline on the stocks of marine fishes around the world. Marine fisheries in many of the countries are exploited unsustainably due to its characteristics of open access situation with ill specified property rights and imperfect market conditions. To compat the decline of fish production, aquaculture is coming ina big way. Aquaculture is one of the fastest developing food-producing segments in the world. All through the years, it has been and still expanding and intensifying. In both area, in capture fishery and in aquaculture the conservation of fishes is a paramount importance. The authorities enforces many legal frame work to conserve the species but at enforcement level it varies. In this process, there are chances many of the species may get endangered in the wild. Fisheries Scientists and conservationists made efforts to conserve the species and many technological advancement are in vogue for conservation of fishes.

Cryopreservation of gamate is one of the important methods for conservation of animals in the world wide. Cryopreservation is of interest not only for fish farming but also for the conservation and genetic improvement of resources. Cryopreservation is a branch of cryobiology which relates to the long-term preservation and storage of biological material at very low temperature, usually at -196°C, the temperature of liquid nitrogen. It is based on the principle that very low temperatures immobilize the physiological and biochemical activities of cells, thereby making it possible to keep them viable for very long period in a state known as 'suspended animation'. Cryopreservation of fish sperm is one method successfully adopted from animal husbandry by the aquaculture industry. Cryopreservation overcomes the problem of males maturing before females, allows selective breeding and stock improvement and enables the conservation of genomes. The basic technique of cryopreservation involves collection of fish gametes in which specific diluent (extender) with cryoprotectant (such as dimethyl sulfoxide, glycerol, ethylene glycol and methanol) is added. After a period of specific of equilibration, it is frozen rapidly and stored in liquid nitrogen. After thawing, the milt can be activated for use in fertilizing the eggs. In teleosts, spermatozoa are held within the testis in an immotile state by the chemical composition of seminal plasma. Under natural conditions, motility is initiated when the semen or milt is diluted with water on release during spawning. During cryopreservation, the sperms are to be retained in inactive condition and it is the extender that keeps the sperm in live but in immotile state so that ideal dilution of cryoprotectant can be made to mix with the milt. Cryopreservation allows virtually indefinite storage of biological material without deterioration over a time scale of at least several thousands of years (Mazur, 1985), but probably much longer.

The scientific underpinnings of cryobiology can be traced back to the 1950s after the discovery of the cryoprotective qualities of glycerol for fowl sperm (Polge, Smith and Parkes, 1949). The first studies of fish sperm cryopreservation were published soon thereafter (Blaxter, 1953), and since then more than 200 species of fish have been studied (Rana, 1995; Tiersch, 2000). Cryopreservation is a process where biological materials such as cells and tissues are preserved by cooling to ultra-low temperatures, typically -196°C (for liquid nitrogen), yet remain viable after subsequent warming to temperatures above 0°C. For sperm cryopreservation, this process typically includes gamete collection, suspension of sperm in an extender, quality assessment, addition of cryoprotectants, equilibration, freezing, thawing and fertilisation, and the development of early life stages for assessment of cryopreservation success (Tiersch, 2000). This technique has been well established in some freshwater fish species mainly, salmonid, sturgeons and carps, and in last two decade research was focused in marine fish species. In India, NBFGR is the primary organization in India carrying out fish sperm cryopreservation for long term gene banking.

Cryopreservation of spermatozoa

The first success in preserving fish sperm at low temperature was reported by Blaxter (1953) who fertilized herring (*Clupea harengus*) eggs with frozen – thawed semen. Major efforts have been made during the past 20 years to effectively freeze salmonid sperm (Stoss, 1983) and now sperm from several species of fish have been frozen. The spermatozoa of several economically important species have been cryopreserved in the recent past which includes rainbow trout, Atlantic salmon, Tilapias, several cyprinids including Common, Chinese and Indian carps. Some economically important marine species for which spermatozoa have been frozen include Asian sea bass, Atlantic halibut, milk fish, black porgy, bluefin tuna, various catfishes, Indian marine fishes. Majority of the works on cryopreservation of fish semen concerns cultivated species or species of commercial interest. Considering the needs to establish gene-banks for endangered fish species and to avoid loss of genetic variability – there is still a need for investigation in the field of sperm preservation.

Extenders:

Undiluted gametes are not suitable for freezing and they must be diluted with a suitable extender. An extender is a solution consisting of inorganic and organic chemicals resembling that of blood or seminal plasma in which the viability of spermatozoa can be maintained during *in vitro* storage. Extender also helps to reduce the toxicity of the cryoprotectant used in cryopreservation. The efficacy of cryopreservation is greatly enhanced if the prefrozen milt is diluted with a suitable extender. Various extenders, containing KCl, NaCl, glucose, sodium citrate, Ringer's solution, cow serum and milk fish serum were used to preserve fish sperm in liquid Nirtrogen (-196°C). The sperm of the Indian carp, *Labeo rohita* were first preserved in liquid nitrogen using extender comprised of NaCl – 730 mg, $NaHCO_3$ – 500 mg, Fructose – 500 mg, Vegetable lecithin – 750 mg, Mannitol – 500 mg, Distilled water – 100 ml.

Cryoprotectant:

Cryoprotectants are added to extenders to minimize the stress on cells during cooling and freezing. Glycerol, DMSO and methanol are the most widely used cryoprotectants for preserving teleost spermatozoa. The optimum concentration used for cryopreservation may vary species to species. However, the degree of success has been achieved with 10-15% glycerol, DMSO or methanol for many species. The optimum cryoprotectant concentration for a given protocol may also depend on the equilibration period that is the time allowed for cryoprotectant penetration into cells. There are two kinds of cryoprotectants namely permeating and non-permeating cryoprotectants. The permeating cryoprotectants include DMSO, glycerol, methanol, ethylene glycol etc. The non-permeating cryoprotectant includes egg yolk, milk and some other protein (Soyabean protein, Promine D and bovine serum album). A non-permeating cryoprotectant is often used in conjunction with a permeating cryoprotectant.

Dilution ratios:

Various milt to diluent ratios have been tested. It is 1:1 to 1:9 in salmonids, 1:3 in rainbow trout and 1:20 in *O. niloticus*. In Indian cyprinids and catfishes, 1:3 and 1:4 ratios were found to be ideal.

Motility:

The spermatozoa of most teleost fish species are immotile in testes and the genital tract and are activated only after release into the external medium for a short period of motility. The initiation of motility of fish sperm is essentially a dilution effect upon expulsion of semen into the surrounding water. Spermatozoa motility in fish is usually estimated by an arbitrary scale of intensity ranging from 0 to 5, by the duration of motility for a given intensity, or by a combination of these two parameters. Sperm motility is one of the most important parameters of sperm quality and is usually expressed in duration of sperm movement and percentage of motile sperm immediately after activation.

Procedure of cryopreservation:

Milt of the fish has to be collected in a dry and clean box and to be kept on ice till it used. The extender has to be prepared afresh every time and the cryoprotectant (@10% of the extender) to be mixed just before filling the straw. The milt extender ration should be kept 1:3. Just after mixing the milt with the extender, cryoprotectant to be added and then straws to be filled. and sealed by poly vinyl alcohol (PVA) powder and keep on ice for 10 minutes for bringing down the temperature to $0^{o}C$. After that straws should be transferred to liquid nitrogen vapour phase ($\sim 90^{o}C$) for 10 minutes and then to be immersed in liquid nitrogen for achieving the desired temperature ($-196^{o}C$). The filled straw then can be stored in liquid nitrogen. The motility of the cryopreserved milt can be checked after thawing straws using an activator solution. After confirming the motility of the cryopreserved milt, it can be used for fertility experiments. Once fertility trials become successful, then cryopreservation of milt is complete. From the experiments one can find out best combination of extender and cryoprotectant and this can be used for long term cryopreservation fish milt.

Technical problems in fish sperm cryopreservation:

The fish sperm cells are small, have no acrosome and are available in enormous quantities is semen for experimentation. Hence, recovering motile, fertile frozen thawed fish spermatozoa is not a problem. Yet, the published information reveals difficulties in developing a reliable and reproducible protocol. The problem is in the enormous diversity of fish spermatozoan physiology.

Although all the species studied are external fertilizers, the behaviour of the adults at spawning and the conditions in which sperm and egg must meet are very different. The two extremes are represented by salmonids spawning in freshwater, where sperm is deposited as close as possible to the eggs and swim for 30 seconds at most and marine species like herring where spermatozoa are released in a diffuse cloud over the spawning grounds and remain motile for hours. In species where spermatozoa swim for long periods in nature, cryopreservation is generally easier. Tilapias are a good example. They can spawn in fresh to full seawater and their spermatozoa will swim for hours in a saline solution. The real challenge facing cryobiologists interested in freezing fish spermatozoa is not recovering enough viable sperm cells to fertilize small numbers of eggs in the laboratory but in making the technique practical in the field. The cryopreservation strategy and technique used at NBFGR is simple, does not need any electrically operated equipment. This provides easy adaptability, customization in difficult remote locations and successful application has been proved in species of various taxonomic groups.

Application of cryopreservation of spermatozoa

Cryopreservation of fish sperm can be successfully used as a fishery management tool. It provides some means of control relative to mating and reproduction including artificial propagation with individuals of same species from the distant locations or of different mature season or developing a profitable new

hybrid. Sperm from males in the wild can be cryopreserved for the optimal mature season of hatchery stock so that genes from the fish in the field can be transferred into the hatchery population. Cryopreservation of fish sperms can be used to guarantee the specific fish stocks and to ensure against the loss of specific genes caused by natural, over-fishing or pollution causing disasters. It can be used in the hatchery management to solve the problem of having a disproportion between the males and the females. Induction of gynogenesis becomes highly feasible if the irradiated sperms are cryopreserved in advance. Functions of sperms and gene bank can be further facilitated by utilising this technique. The benefits of sperm cryopreservation include: (i) synchronization of gamete availability of both sexes, (ii) sperm economy; (iii) simplification of broodstock management, (iv) transport of gametes from different fish farms, and (v) germplasm storage for genetic selection programs or conservation of species. Sperm cryopreservation can give an important contribution in the germ storage of all transgenic lines. Cryopreservation of gametes would certainly benefit from a higher concern on male improvement, basically through nutrition or selection of resistant stocks producing gametes of higher quality.

Conclusion:

Storage of fish spermatozoa, eggs and embryos without loss of viability is of considerable value in aquaculture and conservation. The fish sperm cryopreservation needs development of species-specific protocols. Such protocols are developed through experimental standardization of various parameters, after the captive breeding protocol is developed. This becomes a bottleneck due to protracted breeding season and low domestication of most of the aquatic species, especially marine fishes. Nevertheless, in all such cases, time available in a year for conducting experiment is small and determined by breeding cycle of the species. In view of the constraint, it is essential that candidate species for sperm cryopreservation are prioritized. In artificial propagation, sperm cryopreservation protocol can be an asset where such milt related problems exist. Cryopreserved sperm was also used to retrieve the whole species and clones. Sperm retrieved from fish, stored at -18°C has been used to produce androgenetic fish and interspecific androgenetic cloning, as a mode for restoration of species. Though milt cryopreservation is successful in many fish species fish gamete cryopreservation still faces an important challenge in the form of long-term storage of finfish eggs and embryos. Owing to large size, large amount of yolk and tough chorion or zona radiata with a low permeability coefficient, egg and embryo cryopreservation of teleosts and crustacea have not met with success anywhere in the world so far. The fundamental problem of sufficient dehydration during cooling due to the relatively large size (1-6 mm) of fish eggs and the presence of membrane of different water permeability has not been overcome. Cryopreservation or long term storage of fish eggs or embryos would be beneficial to the aquaculture industry. In general, cryopreservation would provide a method of retaining specific genetic lines of fish without the expense of maintaining brood stock populations and would provide a secondary source of a genetic line in case of brood stock loss or would allow the preservation of endangered genetic line in the wild populations. Recent invention in priomordial germ cells cryopreservation and cell line development and culture succeeded in many fishes. This will also help to conserve the fishes to a great extent.

CHAPTER

13

Stomach Content Analysis Techniques in Fishes

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In Ichthyology, fish ecology & fisheries resource management, the information on diet & food habits are valuable in the decision-making process related to natural resources (Kido, 1996). Fish gut content analysis provides an important insight into feeding patterns & quantitative assessment of feeding habits is an important aspect of fisheries management. Fish diet represents an integration of many important ecological components that includes behaviour, condition, habitat use, energy intake & inter & intra-specific interactions, etc. A valid description of fish diets & feeding habits also provides the basis for understanding trophic interactions in aquatic food webs. Conceptually, trophic relations of fishes begin with the food & feeding habits & gut content analysis can be used to evaluate the habitat preferences, prey selection, effects of ontogeny & developing conservation strategies (Chipps & Garvey 2007). A food habit study might be conducted to investigate the most frequently consumed prey or to determine the relative importance of different food types to fish nutrition & to quantify the ingestion rate of individual food types. All such questions demands information on fish diets & requires different approaches in how one collects & analyzes data. In summary, gut content analysis is used in the understanding of many aspects of fish ecology on individual, population & ecosystem levels. It helps us to study & elucidate specific problems of interactions, evolution, speciation, invasions & fishery management nature protection. As a result, stomach content studies could be incorporated into a variety of different research objectives. Consequently, the study of the gut content is not only way to know the diet but also superior source of information on many aspects of fish biology & ecology.

The study of the feeding habits of fish & other animals based on direct examination of stomach content has become a standard practice for many years (Hyslop, 1980). Recently, many other methodologies such as radioisotopes, stable isotope analysis, direct species observations & fatty acid analysis are currently being used (Braga *et al.*, 2012). These approaches have both positives (more accurate & can reveal even the items which cannot be identified by microscopic study) & negatives (expensive, complicated procedures). However, the direct gut content analysis carried commonly out through dissection or evacuation & examination of stomach contents is still the most used & easiest method with great potential & good enough for most biological/ecological studies (Manko, 2016). Other factors *viz.,* sampling location, time of day, prey availability & even the type of gear used collect the fishes need to be considered before initiating a diet study or analyzing existing diet data for a better understanding of diet data & for accurate interpretation of fish feeding habits (Zacharia, 2017).

Gut contents can be collected either from the live or fresh died or preserved fish. Irrespective of the method, investigators should ensure that, the gut removal technique effectively samples all food items in the gut or else data will be distorted toward food items that are more easily displaced from the stomach. Instead, live fish can also be forfeited & gut contents removed for analysis. When diet samples are not analysed forthwith, fish should be preserved immediately either by freezing or by fixing in formalin to avoid continued digestion of food contents (Chipps & Garvey 2007). Proper care should be taken to encounter more samples which include all size groups of the particular fish since the feeding behavior of juveniles & adults of many fish groups vary significantly. Sampled fish should be measured to its total length to the nearest 1 mm & weight to the nearest 0.1 g, then a make a longitudinal cut on the ventral side of the fish from just behind the isthmus of the gills posterior to the anal fin. Make two transverse cuts at each end of the first cut to open the coelom to expose the viscera & record the sex & maturity stage of the fish. Separate the digestive tract (esophagus, stomach & intestine) from other visceral organs, then judge the degree of distension of the stomach & classify as 'gorged, 'full', '3/4full', '1/2full' 1/4full & trace by eye estimation & note down the weight to the nearest 0.1 g. Stomach contents may be analysed immediately or preserved in 5% neutralized formalin to analyse later. For analysis, a longitudinal cut must be made across the stomach then sever the stomach (or foregut) from the hindgut to avoid the bias when both easily digested prey & resistant prey are present. In fish, Fishes which do not have a distinct stomach, the first half of the intestine can be dissected & the contents are transferred into a petri dish for further analysis. While analysing formalin preserved samples, keep gut contents out or in water on petri dishes for five minutes to remove excess formalin. Analyse the gut content to the genus & up to species level wherever possible by identify the large prey on eye observation & examination of small prey under binocular microscope.

Fish diets are measured in a variety of ways. Gut contents analysis are broadly classified into qualitative & quantitative methods. The qualitative analysis involves a complete identification of the organisms in the gut contents. Only with extensive knowledge & with the aid of good references it is possible to identify prey & other food particles from digested, broken & fine comminuted materials. Quantitative methods of analysis are classified in to three types, *viz.,* numerical, gravimetric & volumetric. Quantitative methods are most discussed problematics in the gut content analysis. Many authors examined these methods, compared & employed the best one for application in the various scenarios & for highlighting different aspects of feeding ecology (Hynes, 1950; Pillay, 1952; Hyslop, 1980; Cortes 1997; Hansson 1998; Liao *et al*., 2001; Chipps & Garvey, 2007; Ahlbeck *et al.,* 2012; Baker *et al.,* 2014 & Manko, 2016). Generally, on the basis of grading & comparing food contents in the fish diets, one presume that some food is more important than others to the growth, survival, recruitment, size structure, condition, reproductive success, or other aspects of the ecology of the fishes, thus it is crucial to describe the true importance of food contents (Bowen, 1996).

1) Numerical methods

The numerical methods are centered on the counts of constituent items in the gut contents. The numerical methods have been adapted in different ways to assess the relative importance of food items & these can be classified under four distinct heads *viz.,* a) Frequency of occurrence, b) Number c) Dominance & d) Point methods.

a) Frequency of occurrence:

Recording the presence or absence of each food item across all individuals is the simplest way to reveal the relative importance of different food items & to judge the dietary composition of a fish population. The importance is inferred from the proportion of total guts containing each food item (Baker et al. 2014). Each food item occurred in number of stomachs is recorded & expressed as a percentage of the total number of fish stomachs examined.

Frequency of occurrence,

$$\% O_i = \frac{N_i}{N} X\ 100$$

Where: % O is the frequency of occurrence of given food i

N_i is the number of stomachs containing prey i

N is the total number of stomachs with some food

Frequency of occurrence method exhibits what organisms are being foraged upon, the advantages are food items are readily classifiable, rapid & requires the minimum of apparatus. However, frequency of occurrence furnish little indication of the relative importance or bulk of each food category present in the stomach.

b) Number method:

The number method is based on the counts of food items in the gut content. The number of individuals of each food category in each stomach are recorded & expressed as a percentage of the total number of food items in all fish stomachs examined or as a proportion of the food items of each stomach of fishes examined, which raised to the total percentage composition (Hynes, 1950). The numerical method is easy & relatively fast.

Percentage by number,

$$\% O_i = \frac{N_i}{N_t} X\ 100$$

Where: % N_i is the percentage of food item i

N_i is the number of particular food item i

N_t is the total number of food (gut content) items

This method has been applied successfully by many workers in studies on feeding habit of fishes *viz.,* plankton feeders & piscivorous, where prey items of different species are in the same size range & the ease of counting individual of countable prey or their appendages like head capsules, carapace, other body parts etc. (Beyerle & Williams, 1968; Guma'a, 1978). In contrast, this method is not practicable & will not yield correct evaluations when the food do not appear in separate units (like detritus, macro algae, comminuted plant matter), the food is masticated or fast digestible because of its nature. (Hyslop, 1980; Scharf *et al.,* 1997; Legler *et al.,* 2010; Ahlbeck *et al.,* 2012; Baker *et al.,* 2014; Zacharia, 2017).

The differences in size of food items are not considered in the number method, similarly to the frequency of occurrence. This method overestimates small prey items taken in large numbers & underestimates large food items like the gut contents of a carnivore which may consist of only one large sized fish & a couple of small larvae. Thus, the number method has very limited use in the studies on the food of fishes other than plankton feeders, when food consists of significantly variable prey (food) size (Ahlbeck *et al.,* 2012).

c) Dominance method:

This method is a further improvement of the occurrence method. The number of fish in which each food item occurs as the dominant food material is expressed as a percentage of the total number of fishes examined (Hynes, 1950). The dearth of the quantities of the food items present in the stomach should be eliminated (Zacharia & Abdurahiman, 2004), but the dominance method gives substantially the same result as in the occurrence method. It is applicable only to count food occurring in discrete units when the dominance is derived from numbers. Therefore, it is questionable if it makes sense to use this method in practice. This method gives only a very rough picture of the dietary of a fish & the food items which are less dominant due to environmental reasons may escape attention. Therefore the dominance of particular item is calculated according to equation if used.

$$\text{Dominance of food, } D_i = \frac{N_{di}}{N} \times 100$$

Where: N_{di} is the number of fish in which food item i dominates

N is the number of fish examined

d) Points (Numerical) Method:

This method is an improvement on the number method where consideration is given to the bulk of the food items. Food items are classified as very common, common, frequent, rare, etc., based on rough counts & judgments by eye. Due importance is also given to the size of the food item during random classification & food contents of all stomachs are tabulated. Different classes are allotted a certain number of points & the summations of the points for each food item are reduced to percentages to show the percentage composition of diet.

2) Volumetric methods

Volume of food is considered as a more satisfactory method by many workers for quantitative analysis of gut contents. The volume of each food item or of the total food of each fish is given in this method. The volume forms a very suitable means of assessment especially in the case of herbivorous & mud feeding fishes where the numerical methods are inaccurate (Hynes, 1950). Even in cases where the numerical methods are appropriate, volume has been considered as an essential aspect to be quantified with, & in all improved numerical methods the volume of the food items is taken in to consideration in some way or other. The volume of specific food item is expressed as the individual food item volume percentage of the total volume of digestive tract contents.

$$\text{Percentage by volume, } \%V_i = \frac{V_i}{V_t} \times 100$$

Where: $\%V_i$ is the ratio of the food item i

V_i is the volume of food item i

V_t is the total volume of food (gut content)

a) Eye estimation method: - Eye estimation is probably the simplest & easiest way of ascertain the volume of food items with only little effort when comparing with other volumetric methods though it suffers from several weaknesses. This method of analysis is subjective in nature & the investigators personal bias is likely to influence the results greatly. This limitation can be minimised by experience/training gained by the analysis of large samples & repeated evaluation of estimated values in the same sample. Eye estimation is a substitute approach to the numerical method when analysing diet with food items *viz.,* plant material & debris which cannot be counted.

b) Points (Volumetric) method: - Points method is a contrast to the eye estimation method. Instead of direct estimation of the volume by sight as in the former method, each food content in the stomach is allotted a certain number of points based on its volume. While allotment of points both the length of the fish & the fullness of the stomach are taken into account by certain workers. Total 16 points are given to the highest volume of the diet component & every other constituent is awarded 16, 8, 4, 2, 1 & 0 points depending on the volume relative to the component with the highest volume. Percentage volumes within each subsample were calculated as:

$$\alpha = \frac{\text{Number of points allocated to component } \alpha}{\text{Total points allocated to sub sample}} \times 100$$

Where: α is the percentage volume of the prey component α

Point's method is more convenient for analyzing herbivores & omnivorous fish diet, where measuring volumes of microscopic organisms such as diatoms & filamentous algae are very difficult.

c) Displacement method:

This method is probably the most accurate one to estimate the volume. The volume of each food item, or of the total food of each fish is expressed as a percentage of the total weight of the fish. The volume of each food content is measured by displacement of water in a graduated container such as a cylinder with the smallest possible diameter for accuracy & could be used for calculation of these ratios (Hynes, 1950). The displaced volume of water is equal to that of the food item. Alternately, volume of the food contents may be measured by allowing them to settle in a graduated measuring cylinder (Hyslop, 1980).

Displacement method is eminently suited in the estimation of the food contents of carnivorous fishes eating larger preys rather than for small/ rare occurring food & the differential rate of digestion of the food items may sometimes affect the accuracy of the observations. However, if fishes caught immediately after feed on, this complication can be overcome. A knowledge of the volumes of the different size groups of the food items may be of great help in estimating of the volume if the whole item is created by semi-digested fragments (Zacharia, 2017). Other problems *viz.,* water trapped within the food may cause large errors in the estimate, food items may change their volume differently in preservation media & presence of large volumes of mucus in some species could make this method more difficult (Baker *et al.,* 2014).

3. Gravimetric method

The gravimetric method consists of the estimation of the mass of each food item, or of the total food content of each fish, which is usually expressed as a percentage of the total weight of the fish as in other quantitative methods. Gut content may be expressed as wet, dry or ash-free dry weight (Hyslop, 1980). The wet weight of the food is measured after removing excess water by blotting with tissue paper to diminish the prejudice caused by measuring food items with water trapped between the food pieces. Contrarily this issue could be evaded by measuring the dry mass of food in the gut content. Dry weight estimation is more time taking & is usually employed where accurate determinations of calorific intake is required. Dried food contents can be weighted when they are big enough to be handled individually & the accurate weighing of small quantities of food matter is extremely difficult & impracticable in studies of large collections (Bowen, 1996). Hence this method is generally employed only in conjunction with other methods to demonstrate seasonal variations in the intensity of feeding. Dry weight is estimated after drying to constant mass by oven-drying at 60 - 105°C for 48 hours. Food samples are cooled down in a vacuum desiccator & then weighed in case of very precise results are needed.

$$\text{Percentage by weight,} \quad \% W_i = \frac{W_i}{W_t} \times 100$$

Where: % W_i is the percentage of food item i

W_i is the weight of food item i

W_t is the total weight of food (gut content)

Table 1. Example of results obtained using different methods of estimation of stomach contents for two *Epinephelus diacanthus*

E. diacanthus 1 (Ed1). 1 *Nemipterus* spp., 6 cm long, weight 10g, volume 12 ml, 1 *Loligo* spp., 3 cm long, weight 8g, Volume 10ml, 9 *Acetes* sp. each 2.5 cm long, weight 350 mg each, Vol. 2ml.

E. diacanthus 2 (Ed2). 2 *Nemipterus* spp., 5 cm long, weight 8g each, volume 24 ml, 5 *Acetes* sp. each 2 cm long, weight 180 mg each, Vol. 1ml.

Food	Method	Fish			%	Total of which % expressed
		Ed1	Ed2	Total		
Nemipterus spp.		1	1	2	40	
Loligo spp.	Occurrence	1	0	1	20	All food occurrences
Acetes sp.		1	1	2	40	
Nemipterus spp.		1	2	3	16.7	
Loligo spp.	Numerical	1	0	1	5.57	All food organisms
Acetes sp.		9	5	14	7.8	

Nemipterus spp.		1	1	2	100	
Loligo spp.	Dominance	1	0	1	50	All fish
Acetes sp.		1	1	2	100	
Nemipterus spp.		12	24	36	73.5	
Loligo spp.	Total volume	10	0	10	20.4	Total food volume
Acetes sp.		2	1	3	6.1	
Nemipterus spp.		50	96	73	73	
Loligo spp.	% volume	41.7	0	20.9	20.9	Food volume
Acetes sp.		8.3	4	6.1	6.1	
Nemipterus spp.		10	16	26	68.5	
Loligo spp.	Gravimetric	8	0	8	211	Total weight of food
Acetes sp.		3.1	0.9	4	0.5	

Food analysis indices

A. Simple indices:

1. Index of fullness (ISF):

Index of fullness express the ratio of food weight to body weight. This index is extensively employed & it could be applied to the food in the stomach, or to that in the whole digestive tract. (The ratio of corresponding volume can also be used.) It is usually asserted as parts per 10,000 (%00, or parts per decimal) & calculated using formula:

$$\text{Index of Stomach Fullness, (ISF),} \quad = \frac{W_g}{W_f} \text{ X } 1000$$

Where: % W_g is the weight of the stomach contents (g)

W_f is fish body weight

2. Index of Preference, Index of Selection, Forage ratio (FR):

Most of the fishes have a degree of selection for the food organisms available in their habitat, so that some are consumed large in numbers, others moderately, some not at all. A quantitative index of such variances called as the forage ratio. The forage ratio developed by Savage (1931) used the percentage of quantity of food item i in the gut as a percentage of the total gut content & the relative quantity of the same food item in the environment as a proportion (percentage) of the total abundance of available food in the habitat. The lower limit for this index is 0 & upper limit is indefinitely large.

$$\text{Forage ratio,} \qquad FR_i = \frac{r_i}{p_i}$$

Where: r_i is the percentage weight of the food item i in the stomach

p_i is the percentage weight of the food item i in the habitat

3. Index of electivity (E), Index of selection, Ivlev's Forage Ratio:

The Electivity index proposed by Ivlev (1961) is slightly different quantitative measure of selection which has been widely used in comparing the feeding habits of fishes. This index uses the relative abundance of food item i in the stomach as a percentage of the total gut content & the relative abundance of the same food item in the habitat as a proportion (percentage) of the total abundance of available food in the habitat. Electivity index was developed to describe the electivity as a degree of selection of particular prey species by predator studied & to avoid the weakness of forage ratio (FR) resulting from the 0 to infinity range. The index has possible range from -1 to +1. Negative values indicated as avoidance or inaccessibility of the food item, zero representing random selection form the environment & positive values indicate active selection.

Ivlev's index of electivity, $E_i = \dfrac{r_i - p_i}{r_i + p_i}$

Where: r_i is the percentage weight of the food item i in the stomach

p_i is the percentage weight of the food item i in the habitat

Though the Electivity index initially assumed as unbiased & relatively independent of sampling size were later, after empirical & theoretical re-evaluations declared as invalid by Strauss (1979). He revealed similar to FR this index also significantly biased when the size samples from the stomach & from the environment are unequal, it is dependent upon sample size (both relative & absolute) & is also not useful for food item not dominant in the environment. This flaw will influence the results concerning rare food items, even though large number of samples are analysed (Lechowicz, 1982). Another issue is the extreme values *ie.,* -1 & +1. The -1 value (total avoidance) can be obtained only in such case, when the food item does not occur in the fish stomach, but occurs in the environment irrespective of how scare or abundant it is. In contrast +1 (the maximal positive selection) can be obtained only in the case when the food item do not occur in the environment, but occurs in the fish stomach, irrespective of how large or small is its proportion (Straus, 1979).

B. Compound indices:

Food content analysis can give us data which helps to resolve more complex questions of fish ecology. This vital information provides in-depth insight to the fish feeding ecology, resources availability & demands, potential competition & other aspects of fish ecology & biology, consumption or predation (Liao *et al.,* 2001). Individual food content provide unique information about relative importance of particular food. They also offer the possibility to express the ratio of individual food item in the diet & some authors employ the percentage by number (%N), weight (%W), volume (%V), & occurrence (%O) to express the relative importance of prey items. %W (or %V) has been the most accepted index among others, to describe prey importance & its relationships with fish well-being & food availability (Hartman & Brandt, 1995; Persson & Hansson, 1999). However many others opined these information do not always indicate the real importance of particular food *viz.,* from the nutritional value point of view. Therefore In an attempt to receive more complex & objective information, & to avoid information loss, researchers developed combine two or more measures into a single index with a belief is that compound indices capture more information than do single component measures (Cortes, 1997; Chipps & Garvey, 2007; Gelwick & Matthews, 2006).

1. Index of Preponderance:

The index developed by Natarajan & Jhingran (1961) gives a single value for each attribute based on frequency of occurrence & bulk of various food items. Index of Preponderance provides a definite & measurable basis of grading the various food elements. The bulk of food items could be assessed by 1. Numerical 2. Volumetric & 3. Gravimetric methods. As the numerical method is biased with the frequency of occurrence, since it magnifies the importance of smaller organisms which may appear in enormous numbers, either volumetric or gravimetric are best to measure the food items quantitatively.

$$\text{Index of preponderance, } IP_i = \frac{V_i O_i}{\text{“}V_i O_i} \times 100$$

Where: V_i is percentage of the volume of food item i

O_i is the percentage of occurrence of given food item i

A comparison of the values obtained permits a ranking of the food items in order of mathematical dominance as an expression of the importance within the diet & authors of Index of Preponderance are convinced it has enormous advantages particularly when studying fish diet in open waters where animals have ingress to various organisms (Mohan & Sankaran, 1988). They also consider it to be an objective & suitable measure of food dominance within the diet. On the other side, the Index of Preponderance technique does not discriminate between the importance of food items by weight or occurrence & it is not suitable for dietary comparisons (Marshall & Elliot, 1997).

Table 2. Example of the Index of Preponderance of food items of *Catla catla* with rankings in brackets

Food items	**Percentage of Occurrence (O_i)**	**Percentage of Volume (V_i)**	**$V_i O_i$**	**$\frac{V_i O_i}{\Sigma V_i O_i}$ X 100**
Algae	30.5	25.2	768.6	37.13 (II)
Crustaceans	21.8	50.5	1100.9	53.17 (I)
Plants	10.5	13.2	138.6	6.69 (III)
Rotifers	6.5	1.6	10.4	0.50 (VI)
Insects	4.2	7.2	30.4	1.47 (IV)
Detritus	7.3	0.9	6.57	0.32 (VII)
Protozoa	1.2	0.6	0.72	0.03 (VIII)
Molluscs	-	-	-	-
Sand & mud	18	0.8	14.4	0.69 (V)
Σ	**100**	**100**	**2070.43**	**100**

As per the results of the Index of Preponderance, crustaceans & Algae comprise 1st & 2nd ranks in *Catla catla*. Followed by plants, insects, rotifers & other food items. Accidental & incidental inclusion of sand, mud etc. may be left out of consideration while grading the food items.

2. Index of Relative Importance (IRI):

This index is widely used in fish diet studies. While calculating IRI, the percentage of frequency of occurrence of each food item (%O) is multiplied by the sum of the percentage by volume (%V), or weight (%W) & percentage by number (%N) to evaluate the relationship of the various food items found in the stomach (Pinkas *et al.,* 1971). IRI is a composite index employed to describe fish diets & ascertain the relative importance of common food categories (Pinkas *et al.,* 1971; Prince, 1975). The three standard dietary measures are used to compute the IRI as follows:

Index of relative importance, $IRI_i = (\%N_i + \%V_i)\ \%O_i$

or

$$IRI_i = (\%N_i + \%W_i)\ \%O_i$$

Where: $\% N_i$ is the percentage of specific food category by number

$\% V_i$ is the percentage by volume

$\% O_i$ is the frequency of occurrence

% Wi is the percentage by weight

Table 3. Example of the Index of relative importance of food items of *Priacanthus hamrur* with rankings in brackets

Food items	$\% N_i$	$\%W_i$	$\%O_i$	$(\%N_i + \%W_i)\ \%O_i$	% IRI
Nemipterus spp.	10.50	28.12	9.87	381.18	5.65 (II)
Acetes sp.	65.2	27.39	63.50	5879.47	87.22 (I)
Cynoglossus sp.	6.30	14.58	9.20	192.10	2.85 (III)
Loligo spp.	4.70	10.59	6.15	94.03	1.39 (V)
Shrimps	4.80	6.80	4.53	52.55	0.78 (VI)
Bregmaceros sp.	8.50	12.52	6.75	141.89	2.11 (IV)
Σ	**100**	**100**	**100**	**6736.33**	**100**

According to the Index of relative importance *Acetes* sp. formed the bulk of the food. Followed by *Nemipterus* spp. & *Cynoglossus* sp. formed 2nd & 3rd most important pry. Though *Bregmaceros* sp. (8.5% N) ingested more than *Cynoglossus* sp. (6.3% N), ranked 4th in prey importance (2.11% (IRI). *Loligo* spp. & other shrimps were the least preferred prey formed only 1.39% (IRI) 0.78% & (IRI) importance.

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CHAPTER

14

Cephalopod Growth in the Fisheries Context

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Introduction

Cephalopods comprising of squids, cuttlefish and octopus, have emerged as commercially important marine resources of the world. Cephalopod abundance has increased over the last six decades, resulting in quadrupling in landings from 1 to 4.71 million tonnes (2015). Many countries have initiated stock monitoring programs of this resource because of the increasing trends in their annual catches. The age composition and growth rate of fishery stocks are among the most important parameters for studying population biology, stock structure, life span and eventually for monitoring and managing the stocks appropriately.

Maximal sizes in cephalopods species may vary not more than a few grams weight as in *Octopus micropyrsus* to nearly 450 kg as in *Architeuthis* spp. Characterizing growth patterns in cephalopods continues to remain an important aspect in cephalopod biology and ecology even after the first published work by Verrill (1881).

Growth in an organism is the increase in size, dimension or mass. It represents the net outcome of a series of behavioral and physiological processes. The estimation of growth rates requires both measurements of size at various intervals of time (age). Existing body of knowledge concerning cephalopod growth is derived primarily from a combination of laboratory rearing studies and fisheries related field surveys of commercially important species. Estimates of cephalopod growth in the wild use various mathematical models to describe patterns of growth, while laboratory studies describe growth under captivity. Several authors have noted extreme variations in the growth of cephalopods in relation to food availability, water temperature, sex, maturity, season and hatching time. The final size attained by adult males and females may vary within a species; also, within groups of siblings reared under identical conditions, hence size may not be a reliable indicator of age in field-caught cephalopods.

Cephalopod growth is estimated by using indirect and direct methods

Indirect methods:

The indirect method involves the analyses of the length frequency data. Dorsal mantle length of cephalopod samples collected from commercial landings or experimental surveys are measured. In squids and cuttlefish, mantle length (along the dorsal surface from the anterior most point to the posterior most end of the mantle) is the standard measurement. In octopus the, mantle length is measured from the midpoint between the eyes to the posterior end of the mantle along the dorsal surface. These length measurements (frequencies) are subjected to modal progression analyses, whereby the growth of a cohort is followed through most of the life-cycle. Since this method involves the identification and interpretation of the different modes, it is highly subjective and are prone to high errors, particularly in situation where there is prolonged spawning behavior. Thus, use of indirect methods for age estimation must be regarded with caution and verification of such data using one of the direct methods is necessary.

Direct methods:

The direct estimation of growth rate in cephalopods are by 1) using tag–recapture in the wild 2) direct observation of growth under captive condition 3) examination of growth rings in hard-structures such as the statolith, gladius, beak, sepion and crystalline lens.

3.1 Tag–recapture of cephalopods in wild

Releasing and recapturing tagged cephalopods is a direct method for arriving at growth rates during the time interval between tagging and recapturing from the wild. Tagging was used since 1920s in cephalopods for investigating vertical and diurnal migrations, besides collecting information on biology, physiology, ecology and stock identity of the investigated populations. Depending on the size range of cephalopods, different types of tags are used, such as Spaghetti tag, Dart tag, T-bar anchor tag, Petersen discs. There are several potential limitations in using these tags, including physical damage to the tagged animal (mantle integrity, swimming ability), tag loss, and the difficulty in using relatively large tag in juveniles. Recapture rates are variable and influenced by level and extent of fishing, tag colour, tag type and tag placement. Reporting rates for external tags can also be highly variable for a wide variety of reasons such as, fisher apathy, resentment towards research and insufficient rewards. The recapture rates of tagged squids are highly variable especially in migratory species like ommastrephids. External tagging experiments on octopus present additional challenges to those for squid and cuttlefish as their dexterity and strength allows them to easily remove external tags.

3.2 Growth under captive conditions

Captive rearing of cephalopods provides information on life cycle characteristics, including growth, feeding and behaviour. Information on cephalopod growth can be derived by recording changes in length and weight at intermittent intervals. Growth in cephalopods is highly variable, as it is affected by various biotic and abiotic factors. The advantage of captive rearing is that growth and life cycles can be measured and monitored under known conditions; environmental factors can be controlled or monitored. This provides sound information on individual growth rate at different ontogenetic stages.

The major disadvantage of captive rearing is that the laboratory conditions are unnatural or artificial. The impact of predation on behavior and feeding is removed, while population density compared to the natural levels is increased due to crowding. Indeed, most of the available information on octopod growth over their life cycles have come from laboratory rearing. Several problems limit a wide application of this method. Not many cephalopod species have been successfully reared in captivity for the entire life cycle, mostly due to a considerably high mortality rate at the early stages.

In spite of these negative constraints, studies performed on reared animals helped to understand growth performance in several species and were used to validate the time interval necessary for the formation of growth increments in statoliths and gladii.

3.3 Examination of growth increments in hard-structures

Several studies on cephalopods globally have estimated age based on interpreting periodic growth increments in hard-structures over the lifetime of the animal. The criteria to be fulfilled for successful age estimation of hard-parts include:

1. The hard-structures must contain interpretable increment structures that are sufficiently clear to facilitate precise interpretation
2. Increments can be correlated with a regular and determinable time scale
3. The formation of increments continues at a measurable rate throughout life; and
4. The increments are permanent and not resorbed during remobilization of hard tissue.

There are a number of hard-structures in cephalopods which grow throughout, and may be considered as archives of their life cycle. The statoliths, gladii, beaks, stylets and eye lenses are found to bear periodic growth increments within their microstructures and are used for growth estimations.

3.3.1 Statoliths

The statoliths are paired calcareous concentrations within the statocyst of the cephalopod cranium. In cephalopods, statocysts detects gravity, angular accelerations and low-frequency sound. The teuthoid and sepioid statoliths are composed of calcium carbonate in aragonite form, intergrown with thin matrix of organic compounds, which consist mainly of high-molecular proteins.

Statoliths grow continuously throughout their life and are capable of recording life history events useful for stock assessment. In most cephalopods they form concentric rings visible under a light microscope, originating from a periodically changing amounts of organic material incorporated into the aragonite crystal. The better increment visibility is observed with increased incorporation of organic material in statoliths. The shape of the statolith varies markedly between species.

The statolith preparation and processing consist of extraction, cleaning and preservation, preparation of statoliths for age estimation, interpretation of growth increments and image analysis.

- **Extraction:** The squid head is cut between the muchal cartilage and dorsal proximal V-ridge, without causing any damage to the liver initially. The statocysts are then exposed by surgically dissecting the severed squid head in the frontal plane. The statocysts are dissected transversely and the statoliths are extracted manually using forceps.

- **Cleaning and preservation:** The tissue fragments attached to the statoliths after dissection are removed prior to mounting for proper observation. The extracted statoliths are cleaned carefully using mounting needle and fine forceps. They are preserved in vials containing ethanol.

- **Preparation of statoliths for age estimation:** Statoliths are mounted on glass slides using thermoplastic glue for grinding. After drying, the statoliths are ground using lapping films. The ground statoliths are observed under binocular microscope continuously for completely grinding the opaque area.

- **Interpretation of growth increments:** Statolith samples for each major category of size and state of maturity are set aside for age reading. Growth rings are counted using the binocular microscope by changing the focal plane under higher magnifications. High-resolution photomicrographs are difficult to produce, because not all growth increments occur in the same focal plane under high power. Therefore, images are captured continuously for creating a montage of light micrographs for further reference.
- **Image analysis:** Image analysis systems are not commonly used for statolith studies. However, the use of electronic cursor is easier and more accurate than visual counting. Measurements of statolith radius and increment widths are recorded using software. Image enhancement using the software improved the visibility of the increments.
- **Information from optical analysis:** The growth rings in statolith microstructures in many squid species are validated as 'one growth increment-one day' using chemical marking. Maintaining squids in closed culture system for validation of growth is difficult for certain species, therefore, given the similarity of growth increments in validated species with those in invalidated closely related species, the validity of 'one growth ring, one day' hypothesis is generally accepted. The total number of growth increments within the statolith microstructure represents the age of an individual squid in days. More than 52 species of commercial squids of the world oceans have been aged.

The effects of growth, mortality and recruitment act in combination on the population size frequency, and separating them requires independent information for at least two of these variables. The information on the date of capture, spawning and probable recruitment time are used for the interpretation and analysis of the increment data.

3.3.2 Gladius

The gladius is the internal shells of squid (suborders Oegopsida and Myopsida) and bobtail squid (order Sepiolida). Typically, it consists of inner, intermediate, and outer shell layers, but there are variations with respect to the number of layers in some families. These layers grow periodically and the increments or the striae are used in age estimation. Gladius processing for age estimation can be divided into four stages: extraction, preservation, sample preparation and reading. The intermediate layer is the most promising gladius layer for ageing studies.

3.3.3 Stylets

Statolith and gladius analyses of octopus species are unsuitable for ageing. The increment analysis in the hard rod-like vestigial shells or the stylets are used for ageing octopus. However, stylet increment analysis is not suitable for all octopus species because of variation in stylet structure and increment readability.

3.3.4 Beaks

The beaks are basically composed of a chitin–protein complex. Growth process takes place from the posterior border of the beak, where the most recent chitinized and hydrated material is deposited. Growth increments in cephalopod beaks were reported for the first time in the 1960s for the squid *Onykia ingens* using the inner surface of lateral walls. Beak increments have been used for age estimation in squid species in which daily deposition was confirmed by comparing with statolith-determined ages. Beak microstructure increment analysis is affected by processes such as feeding that wear down the beak, resulting in inaccurate estimates.

3.3.5 Sepion

Most attempts to age cuttlefish have concentrated on the cuttlebone. This structure functions as a dorsal backbone providing both support and buoyancy control. It consists of a thin, hard, calcified, dorsal shield and a ventral porous phragmocene comprised of numerous narrow chambers, delineated by chitinous septa. The cuttlefish controls its buoyancy by moving gas or liquid into or out of the chambers as required. As the cuttlefish grows, further septa are laid down at the anterior end. Early studies concluded that the periodicity of chamber formation was daily, however, recent studies found it was related to growth rate rather than chronological age. The growth rate of cephalopods is strongly influenced by temperature and food availability and thus subject to seasonal fluctuations. The width of individual chambers also varies with growth rate.

3.3.6 Crystalline lens

Few attempts have been made for tentative ageing of cephalopods with unreadable statoliths, like in octopus, from their crystalline eye lenses. They grow continuously throughout life by the addition of concentric layers of fibre cells to their outer surface. The stained histological sections of lenses are observed for growth rings after decalcification and dehydration.

Summary

Determination of both age and growth are critical to understand the life history of harvested species and to model the dynamics of their populations, both of which are essential for assessment and management purposes. Successful age estimates have been achieved for many squid species by counting validated concentric daily increments found in statoliths. Recent years have seen the emergence of extensive studies of myopsid squid growth of the family Loliginidae. This has greatly advanced our understanding of their life histories. Growth data have accumulated from both statolith-based field studies and culture work. Validation studies on loliginids continue to support that statolith increments are laid down daily.

Ageing cuttlefish from statoliths has been less successful. In cuttlefish, the growth increments have proven difficult to distinguish due to the irregular and concentric deposition of the aragonite crystals, which result in a strong radial appearance, and the lower percentage of organic matter, which results in weak dark rings. Statoliths of octopods contain randomly arranged statoconia, without any visible increments. This technique has failed to provide results for octopus due to the lack of growth rings and the morphology of octopus statoliths not possessing the same landmarks as those of squid and cuttlefish, which minimizes increment visualization. Stylets, however, do have concentric rings and have been validated for age estimation using *Octopus pallidus* of known age reared in captivity. At present there is no generally applicable method of age and growth determination for all cephalopods and several techniques are in their infancy necessitating continued research in finer refinements and validation.

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CHAPTER 15

Integration of Spatial Attributes in Fishery Biological Studies: The Paradigm and a Case Study of Large Pelagic Fishery In the NW Coast

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Need for spatial data in fisheries research and resources management

Wide spatial distribution and temporal variations in abundance are unique features of fishery resources (Vivekanandan, 2005). The spatial variability of the stock reflects the pattern in fishing effort, thereby the fishing mortality owing to the target stock being aggregated or due to management restrictions, distance to port, vessel size, and the experience and habits of individual fishers (Yong, 2014). Ignoring this spatial variation can lead to serious biases in estimates of fishing mortality and yield (Hart 2001). Indexes related to catch rates or abundances are used often in the stock assessments or are the indexes for monitoring fish stocks despite the fact that the non-random spatial distribution of fish and fishing effort makes the interpretation of commercial catch rate (CPUE) difficult (NRC 1999). Such targeted deployment of fishing effort results in constant or increasing CPUE even though the stock size is decreasing till a point where the stock is at very low levels. A number of fish stock shave collapsed due to such misinterpretation of CPUE, the prominent being the case of northern cod (Hilborn and Walters 1992). These clearly points to the fact that understanding the spatial dynamics of a fishery is an important issue in fisheries management. The management that does not consider the spatial dynamics of a fishery may be less successful in optimising harvest and building an understanding of the interactions between the fishery and other environmental variables (NRC 1999, Hart 2001).

Many of the fisheries management tools generally have spatial component either explicitly through time and area closures, or implicitly through allocation of quota to regions or to fleet sectors with different distributions. Spatial management tools have also been used to protect spawning aggregations, to reduce bycatch, or to meet other single-species objectives. Paradoxically, often, the indexes used for arriving at the management practices as well as for monitoring the management tools are derived from the traditional non-spatial population dynamics models (Pauly et al., 2003). Spatial management measures such marine protected areas (MPA) protect critical habitats from destructive fishing practices, provide insurance against unforeseen ecosystem impacts of fishing, and protected critical life stages of harvested species. Hence, indicators used for evaluation and monitoring of spatial management tools need essentially be spatial

Ecosystem-based fisheries management (EBFM) aims to sustain healthy marine ecosystems and the fisheries they support. It has been developed to move beyond single species management by incorporating ecosystem considerations for the sustainable utilization of marine resources. Ecosystems are spatially heterogeneous and spatial patterns and processes are important to ecosystem structure and function though the distribution of fishing activities depends on distribution of the targeted resource (which in turn depends on oceanographic habitat and interspecific interactions) as well as economic considerations. The species-habitat associations play an important role in ecosystem management, whereas these associations rarely connect with the stock assessment efforts mainly due to lack of spatial information needed to relate habitats to fisheries surveys and fishing effort.

Spatial aspects of fisheries will have very high priority in the alternatives postulated to the present regime of fisheries science and management (Martin, 2004). Use of Geographical Information System (GIS) in decision-making and policy development is growing in many fields and it has a great potential to contribute to the 'spatial turn' in marine fisheries science and management. Two major foundations of the paradigm are acquisition of data (spatially explicit) and scientific analysis. A paradigm shift towards GIS based marine fisheries decision-making warrants radical change in approach of the scientific and management institutions.

Marine Spatial Planning (MSP), a process developed from the bottom up to improve collaboration among all coastal and ocean interests, and to better inform and guide decision-making that affects their economic, environmental, security, and social and cultural interests. Fisheries are not usually fully integrated in the MSP and the often-cited argument for the non or partial integration is that the data on spatial demands of fish and fisheries cannot yet be provided in a spatial and temporal quality adequate for MSP purposes. However, research on integration of fisheries into MSP has gained momentum recently (Janssen *et al*., 2018). The Great Barrier Reef Marine Park zoning, which gives spatial designation for fisheries and other human uses,is a good example for integration of fisheries in the MSP.

The Practice and the Way forward

Fishery dependent data is the major source of information used for deriving the management measures globally though fishery independent, survey based assessments are also used by few developed countries. Spatially explicit effort data for fisheries remain comparatively sparse and are often concentrated around the industrial fleet, relying on electronic logbook-ID-type tracking systems such as VMS (Vessel Monitoring System) and AIS (Automatic Identification System). Such information is scanty from the artisanal and small scale fisheries. The artisanal or small scale nature of the fishery and lack of documentation and self-reporting by the fishers is the major hurdle in recording the spatial data of fisheries in developing countries like India.

The only spatial measure used for management of marine space in India is the MPA, designated for conservation of sensitive organisms or habitat. Lack of spatially-explicit information on the fisheries is the major lacunae in using spatial measures in fisheries management. The National Marine Fisheries Policy-2017 calls for several management interventions for sustaining the fishery like species-specific and area-specific management plans comprising of spatial and temporal measures.The Policy has noted the significance of Marine Spatial Planning (MSP) in view of the competing demands for ocean space.The CMFRI have initiated research projects for gathering spatial data on commercial fisherieson participatory mode and so far spatial information on fisheries of Karnataka, Gujarat, Andhra Pradesh etc. have been documented. The advancements in the satellite technologies for communication and tracking can aid monitoring of vessels for fishing areas, pattern and tracks. Integrating this with the vessel based log-books; on-board as well as port-observers together with the use of electronic devices for real-time reporting can pave way for development of spatially explicit information base on the commercial fisheries of India.

Spatially referred Data Acquisition: Indian context

In a fishery dependent study, spatially referred catch data can be collected only with the active and voluntary participation of the fishermen. Identifying a respondent fisherman is a tricky job needing good acquaintances of the fishing harbour or landing center and players and the processes therein and rapport building. When in the harbour, the fishermen generally will be busy carrying out the unloading of catches and trading amidst planning for the next voyage and they generally will be reluctant to respond to queries. Hence, timing the meeting with the fishermen is crucial for successful negotiations. Skipper (Tindel) of the vessel is the ideal person for engaging in data recording as he oversees the shooting and hauling processes while managing the vessel from the wheel house. Identify and negotiate with the skipper of the fishing vessels, installed with GPS on board. Most of the multiday vessels and some single day vessels carry GPS on board nowadays.

The data collection schedule should be simpler and prepared in vernacular language for convenience of fishermen. Schedule should essentially have fields for noting the coordinates (latitude and longitude) of shooting / setting and hauling and date /time of shooting/hauling, depth of the area etc. A list of expected species (local names) be provided with fields against each for noting the quantity (nos or Kg) caught. Additional blank fields may be provided for noting the details of fishes if any beyond the list and for other special observations. Fields for noting the general weather, sea condition (visibility, current (strength and direction)) etc if provided can fetch additional information though it will be comparative and qualitative. Individual schedules sufficient for the voyage period clipped to a file may be provided in the beginning of each voyage. The filled in schedules should be collected back on their arrival at port preferably prior to unloading the catch and have a quick glance for the species and quantity recorded. This would facilitate observation of the species composition and quantity landed by the vessel helping in validation of the data reported by the skipper.

Data Entry, Validation and Analysis

The data collected may be entered in to a database date wise/operation wise. The database should have provision for entering all the information (qualitative and quantitative) noted by the fisherman. Relative accuracy of the fishing points may be ascertained by plotting the fishing points in any GIS software or Google Earth. Outlier fishing points if any can be identified by this process for elimination or correction. Outliers occurred due to faulty GPS position reading or recording can be rectified in consultation with the fisherman or eliminated. There are several GIS software that can be used for detailed analysis and presentation of the results. Q GIS, Arc GIS, Geomedia etc are few popular GIS software used in marine applications.

Case Study: Spatial features of Large-mesh gillnet fisheries off Gujarat- Important fishing grounds, sensitive areas and interaction of non-tuna and ETP species with the tunas.

The Setting

Large-mesh gillnet based fishery for the large pelagic is a major fishery along the coasts of Saurashtra in Gujarat next only to the trawl and Dolnet fishery. They carry out multiday fishing generally for 3-7 days in a voyage and use gillnets made of multifilament nylon (poly amide) nets of over 2500 m with mesh size of 140 mm. The fishermen set the net once in a day at dusk and haul it back at dawn the following day with a soak time of nearly ten hours. A participatory study was conducted to understand the spatial features of the gillnet fisheries in collaboration with three fishing boats and spatially explicit fisheries data were collected during 2011-16. The study revealed many features of the gillnet fisheries in Gujarat. The succeeding paragraphs brief describe the approach, methodology and few results of the participatory study.

Data Acquisition and Analaysis

Customized log sheets in Gujarati were provided to three selected large-mesh gillnetters at Veraval fishing harbour where a large fleet of large-mesh gillnetters operate. The log sheets had fields for noting date and time of operations, GPS position of shooting and hauling the net, details of catch (approximate weight) including species composition, *etc*. The fishermen were provided log sheets before the commencement of every voyage and the filled-in log sheets were collected back on completion of the fishing voyage.

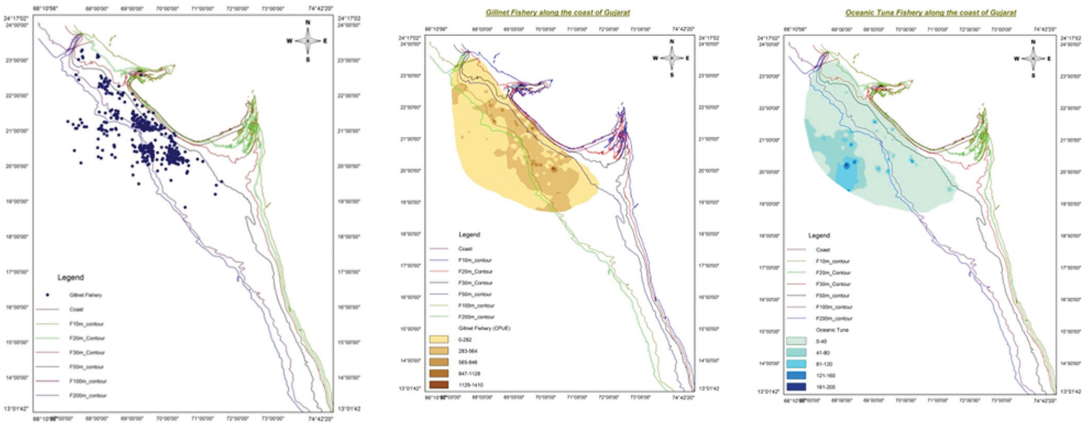
The information provided by fishers were digitized on an MS excel 1997-2003 format compatible to GeoMedia Professional 2014 GIS platform date-wise. Accuracy of the fishing positions were checked by overlaying the points in Google Earth as the position and the track of fishing in the voyage revealed relative accuracy of the data. Catch composition were verified by port observation. The fishermen were consulted at regular intervals using the graphical outputs of preliminary analysis during which the catch information and fishing points were ratified and outliers if any were removed. Species composition and seasonal variations were analysed using MS Excel as well as one way ANOVA. Statistical techniques like Tukey's*post hoc* analysis, Pearson's correlation analysis, hierarchial cluster analysis etc. were used for understanding the variations and relationship among catches. GeoMedia Professional 2014 and its extensions were used to create a georeferenced map for the abundance and distribution of different groups/species etc.

Results

The major target resource of the fishery is the tunas, especially the neritic tuna species-the longtail tuna (*Thunnus tonggol*) and Kawakawa (*Euthynnus affinis*). Quantum and species composition of the catch varied with the area of operation and the season. Seer fishes, queen fishes, mahimahi, cobia etc also formed considerable catches in the neritic areas while the resources like oceanic tunas and billfishes constitute catch in the fishing operations near or beyond the continental break. Incidence of oceanic resources in the fishery is relatively higher during the winter months. Unicorn leather jacket (*Alluterus monoceros*), a neritic, reef associated resource formed considerable catches in the peak winter months. Trigger fishes, wolf herrings, moonfishes, remoras etc formed the low value bycatches besides occasional incidences of endangered species like the turtles and dolphins. The spatially referred catch data obtained by the study revealed the intricacies of the variation in catch composition of gillnet fisheries over time and space, bycatch and discards in the gillnet fisheries, spatial and temporal patterns of the fishery and gave an idea on the movement of the target and bycatch species in the fishing grounds.

Spatial features of the large mesh gillnet fisheries

The study revealed that the operational area of gillnetters of Gujarat is limited to the continental shelf along Gujarat and the adjacent oceanic region between 18°N and 23°N latitudes at depths ranging from 14 m to over 3000 m (Fig. 1). Majority of the effort was expended on the shelves off the Saurashtra coast between 20°N and 22°N latitudes at 50-100m depth zone and only 17% was expended in the oceanic areas *i.e*. beyond the continental shelf break at around 200m depth contour. Fishing in the oceanic areas were mainly during late winter (February) and summer months (March-May). The Fig. 2 provides the species composition and the seasonality of the catches.



Gillnet fishing points	Coastal tuna grounds	Oceanit tuna grounds

Fig. 1. Spread of fishing points of the observed gillnetters and major grounds for coastal and oceanic tunas

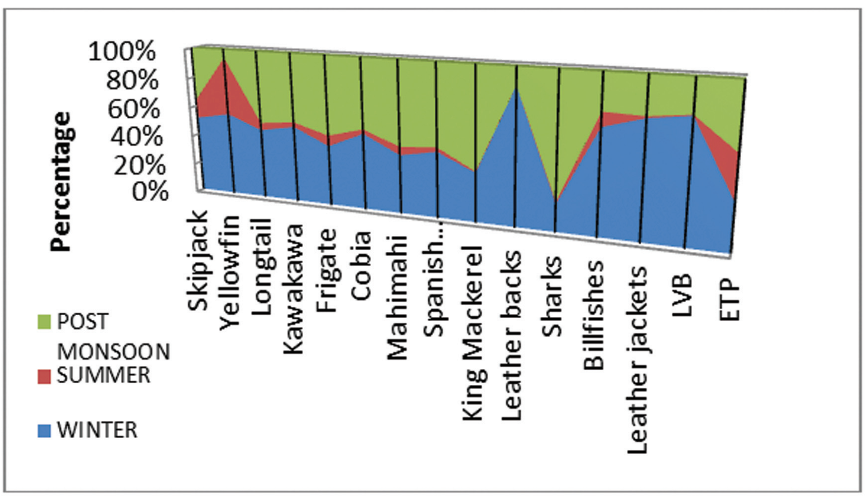


Fig. 2. Species composition in gillnet fisheries and its temporal variations

Interaction of Tunas with the non-target species

The catch covered 16 taxa comprising of tunas (64.62%) and non-tuna species (35.26%) (billfishes, seer fishes, cobia, mahimahi, queen fishes and leatherjacket and low value bycatch (LVB) comprising of less valued fishes such as clupeoids (wolf herrings, shads, etc), needlefishes, flying fishes, triggerfishes, remoras, moonfish, eels, etc.) and ETPs (0.12%) comprising of turtles and dolphins. Neritic tuna formed nearly 92% of the total tuna catch. Three distinct clusters; (1) oceanic tuna and neritic tunas, (2) leatherjackets and other non-tuna species; and (3) ETP were visible. The ETP species exhibited a weak (49.18%) similarity with all other resources (Fig.3). Tuna (neritic and oceanic) and non-tuna catch (leatherjacket and other non-tuna species) showed 53.31% of similarity. The similarity percentage between the tuna groups observed was 56.52%, depicting a distinct difference in the neritic and oceanic tuna catches. The leatherjacket and other non-tuna species were having maximum (71.29%) similarity.

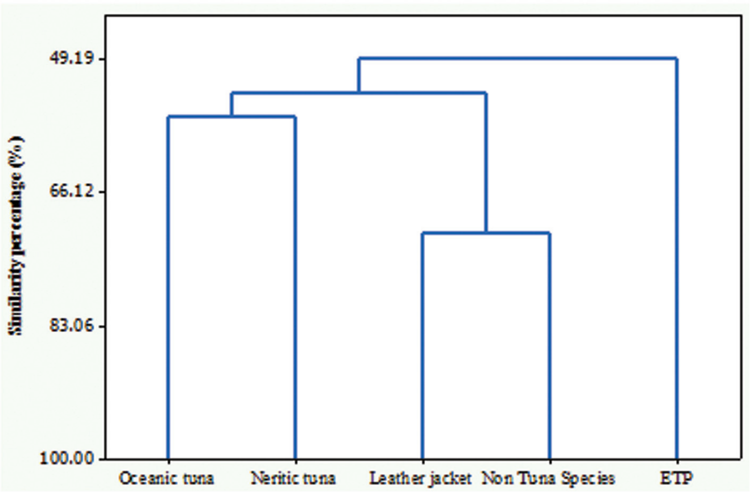


Fig. 3. Results of cluster analysis

Near exclusivity in abundance of unicorn leatherjackets, especially in winter months was observed with the catch of the species forming over 70% of the total in operations were the species dominated the catch (with the remaining being the LVB). Abundance zones of the species indicate clear seasonal pattern with winter being ranked the highest in the Kruskal-Wallis test followed by post monsoon. There was a depth preference by the species with the fish occurring only beyond 30m depth zones and being dominant at the depth zones 51-100m (Fig. 4). There was one major zone of abundance at the depth between 51-100m off south Saurashtra and a minor zone of congregation off Porbander (Fig.5). This uniqueness in abundance patter of the species provoke to study the ecological and oceanographic forcing guiding it and the study is underway to unravel the mystery considering the niche it occupy.

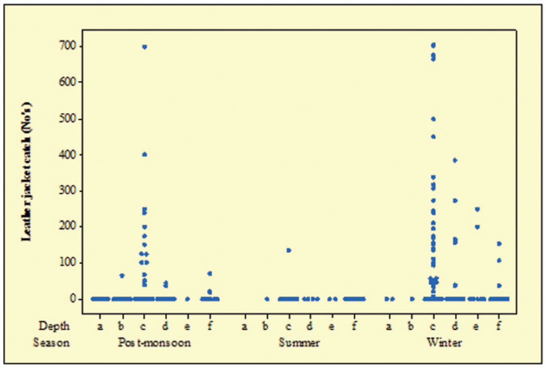


Fig. 4. Dot plot of leatherjacket catches in gillnet across the seasons and depths (a=, 30m, b=31-50m, c=51-100m, d=101-200m, e=201-300m and f=>300m)

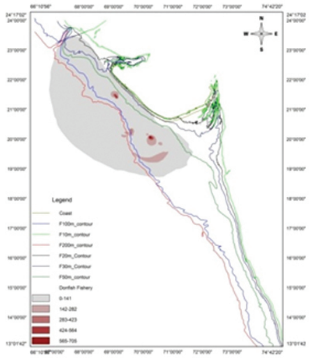


Fig. 5. GIS Map depicting the Fishing grounds of *Alluterus monoceros*

ETP incidences and sensitive grounds off Gujarat

The ETP species- turtles and dolphins occurred only in 4% and 10% of the fishing operations respectively with a catch rate of 0.05 and 0.11. Dolphin incidence in gillnet was more during summer months while turtle incidence was less during summer months and more in post monsoon months (Fig. 6). Turtle and dolphin incidence points were distinctly limited between 20°00N and 21°30'N which falls off central Saurashtra region. Turtles occurred in all depth zones with the abundance being more between 30m and 100m depth contours while dolphins occurred at deeper waters close to 100m and beyond 200m depth contours.

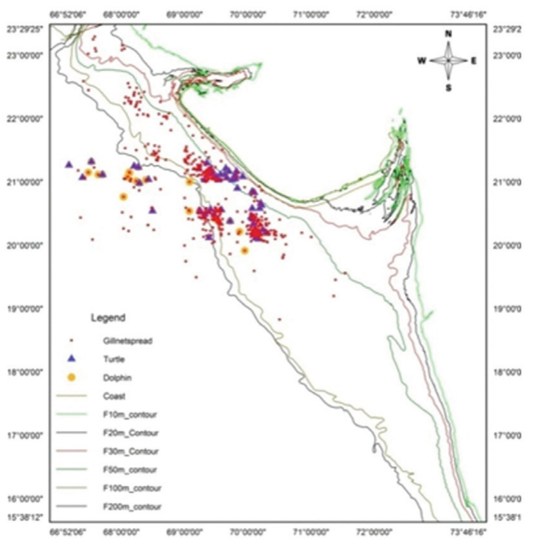
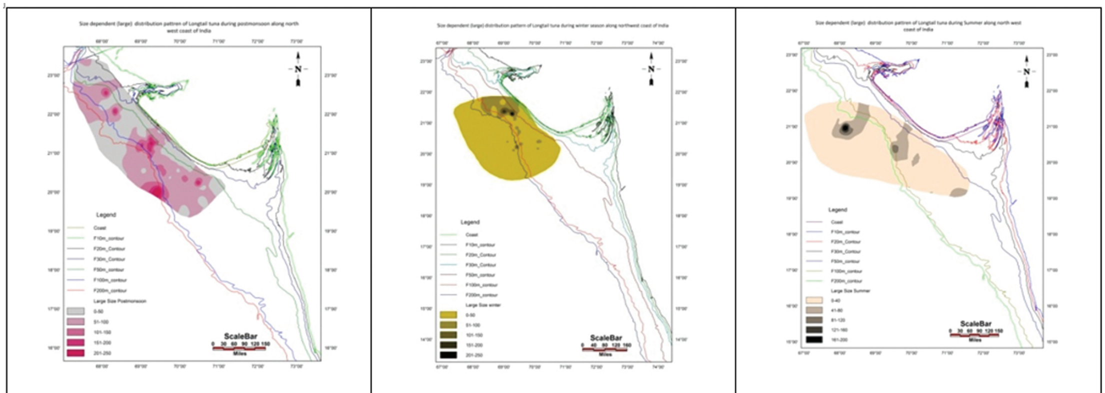


Fig. 6. Spatial points of incidence of ETP species in gillnet fishing off Gujarat

Hints of potential Spawning Area

Longtail tuna, one of the neritic species has a very unique distribution pattern globally; limiting to the continental shelf areas of large landmasses in the Indo-Pacific. All through the distributional range and fishery, ready to spawn females or males were seldom reported from any gear indicating the movement of the spawning population from the fished areas. A spatial study of the tuna fishery off Gujarat depicted abundance of large size fishes beyond the continental shelf areas during the summer months (Fig 7); the period of gonadal development and spawning, affirmed the offshore movement of the species for spawning akin to the reports from the South Pacific and elsewhere in the northern Arabian Sea through landing based biological studies.



Post Monsoon	Winter	Summer

Fig. 7. Seasonal pattern of abundance of adult longtail tuna off Gujarat

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CHAPTER 16

Importance of Fishery Certification - Blue Swimmer Crab (BSC) in Palk Bay Towards the Process

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Introduction

MSC certification confirms whether the fishery is well-managed and is sustaining resources and livelihoods for future generations. Being MSC certified means meeting the world's most recognised benchmark for sustainability: the MSC Fisheries Standard. The MSC Fisheries Standard is based on the United Nations Food and Agriculture Organisation's (FAO) code of conduct for responsible fisheries. The Standard is developed in consultation with a range of people and organisations around the world, including government academics, researchers, the fishing industry and NGOs.

MSC certification may provide

- **enhanced reputation**
- **better visibility**
- **improved dialogue with stakeholders**
- **a pathway for improvements**
- **protected livelihoods**
- **access to new markets**
- **secure markets**
- **promotional opportunities**

What is MSC?

The **Marine Stewardship Council** (**MSC**) is an independent non-profit organization which sets a standard for sustainable fishing. Fisheries that wish to demonstrate they are well-managed and sustainable compared to the science-based MSC standard are assessed by a team of experts who are independent of both the fishery and the MSC. Seafood products can display the blue MSC ecolabel only if that seafood can be traced back through the supply chain to a fishery that has been certified against the MSC standard.

The mission of the MSC is to use its ecolabel, for which the MSC receives royalties for licensing it to products, and fishery certification program to contribute to the health of the world's oceans by recognizing and rewarding sustainable fishing practices, influencing the choices people make when buying seafood, and working with partners to transform the seafood market to a sustainable basis.

When buyers choose MSC-certified fish, well-managed fisheries are rewarded for sustainable practices. In turn, the growing market for certified sustainable seafood generates a powerful incentive for other fisheries to demonstrate they are fishing sustainably or to improve their performance so that they too can be eligible for MSC certification. In this way, the MSC program helps to harness market forces to incentivise positive environmental change.

The MSC Fisheries Standard

The MSC Fisheries Standard is used to assess if a fishery is well-managed and sustainable. The Standard reflects the most up-to-date understanding of internationally accepted fisheries science and management. We review and develop the MSC Fisheries Standard in consultation with scientists, the fishing industry and conservation groups.

How is it used?

When a fishery is successfully certified to the Fisheries Standard, its certified catch can be sold with the blue MSC label. Certification to the MSC Fisheries Standard is voluntary. It's open to all fisheries who catch marine or freshwater organisms in the wild. This includes most types of fish and shellfish. Fisheries are assessed by accredited independent certifiers called Conformity Assessment Bodies (CABs) – also called certification bodies.

What is assessed?

The MSC Fisheries Standard has three core principles that every fishery must meet.

1. **Sustainable fish stocks**

   Are enough fish left in the ocean? Fishing must be at a level that ensures it can continue indefinitely and the fish population can remain productive and healthy.

2. **Minimising environmental impact**

   What are the impacts? Fishing activity must be managed carefully so that other species and habitats within the ecosystem remain healthy.

3. **Effective fisheries management**

   Are operations well managed? MSC certified fisheries must comply with relevant laws and be able to adapt to changing environmental circumstances.

Fisheries Certification Process

The Fisheries Certification Process (FCP) accompanies the Fisheries Standard. It sets out how the MSC Fisheries Standard should be interpreted by certifiers during assessments.

These requirements make sure that the Standard is applied equally to fisheries around the world, regardless of species, fishing method, environment or size. They also give certification bodies the guidance and support they need to assess a fishery against the Fisheries Standard.

(For step by Step details refer MSC Guide – "Get Certified"-23p.)

Indian Scenario

The community-based Ashtamudi short-neck clam fishery (*Paphia malabarica*) is the first MSC certified fishery in India and it is only the third fishery in Asia to have received this recognition. This mile stone been achieved through the efforts made by WWF-India, the Central Marine Fisheries Research Institute (CMFRI) and the Kerala State Fisheries Department, working hand-in-hand with the local fishing community. Short-neck clam fishery contributes to the 90% of the total clam export from India and Ashtamudi Clam Governing Council is the first in India for managing a living resource (Source: www.wwfindia.org).

Blue Swimming Crab (BSC)

Currently few more Indian species are in the process of certification and during 2017, MSC has identified few Indian species, and the Blue Swimming Crab, *Portunus pelagicus* is in the Priority-I list. Further, Indian Crab Meat Processors Association (CMPA) has resumed their work in this line, which has initiated in later period of 2013 with the following objectives.

- To carry-out a MSC Fishery Improvement Project (FIP) for the Gill net Blue Swimmer Crab fishery.
- To Conduct a fishery assessment, organize stakeholders, and formalize a multi-faceted Work Plan that seeks to improve industry sustainability.
- To apply fishery management systems that ensure that blue swimmer crab populations remain productive, and those that rely on the resource remain economically viable now and in the future.

Figure 1. Blue Swimmer Crab – fresh landings from trawls at Mandapam (Palk Bay)

National Fisheries Institute (NFI) Crab Council was formed in 2009 and is comprised of 17 member companies representing more than 85% of the blue swimming crab imported into the U.S. The sole purpose of the Council is to encourage and support efforts to improve blue swimming crab fisheries. The council is funding CMPA to carry-out a Fishery Improvement Project (FIP) following the guidelines in association with all the stakeholders of the fishery which ultimately ensure that blue swimmer crab populations remain productive and remain economically viable to the beneficiaries for a long term. Apart from the fishers and Processors, other important stakeholders are CMFRI (Research Partner providing inputs for the management strategies), WWF (as FIP Co-ordinator - for planning and coordinating the various activities of the all the stakeholders), State Fisheries department officials for the implementation and monitoring the management plans.

BSC fishery is now completed Pre- assessment (PA), the first step towards certification, which is an optional preliminary review to inform whether your fishery is ready to enter full assessment. During a pre-assessment, the assessor will identify the strengths and weaknesses of the fishery in relation to the MSC's 28 performance indicators and allocate an approximate score for each PI. Their results will be used to determine the likelihood of your fishery meeting the MSC Fisheries Standard. The pre-assessments are carried out by an accredited independent certification body. At the end of the pre-assessment, the certification body will present you with a pre-assessment report which identifies any obstacles that need to be addressed before your fishery enters full assessment. The pre-assessment report remains confidential between the party and the certification body and the concerned team can take own decision whether to proceed to full assessment.

The pre-assessment will consist of:

- A meeting between the fishery client and the certification body
- A site visit (this is optional during the pre-assessment stage)
- A review of available data
- Identification of any stakeholder issues or interests
- A pre-assessment report outlining the extent to which your fishery meets the MSC Standard
- A description of potential obstacles that will need to be addressed before your fishery meets
- the requirements of the MSC Standard

Fishery Improvement Projects (FIPs)

An increasing number of fisheries are making the necessary changes to become sustainable with the hope of achieving certification. This has led to considerable growth in organised efforts to improve fisheries, often called 'Fishery Improvement Projects' (FIPs). If the results of the pre-assessment indicate that your fishery is not meeting the MSC Standard, tools and technical assistance are available to help your fishery make the improvements required to meet the standard. Once the areas needing improvement have been identified in your pre-assessment report, the next stage is to develop an action plan for improvement. We have developed an Action Plan for Improvement Template which can be used to lay out and report what needs to be done, by who and when. Successful FIPs rely on the support of stakeholders, including retailers, governments, NGOs and funders. The MSC Benchmarking and Tracking Tool (BMT) can be used to track the progress being made by fisheries as they improve towards sustainability, and help stakeholders understand the status of the FIPs that they are engaging with.

Fishery – Background

The demand for *Portunus pelagicus*, commonly known as Blue Swimming Crab (BSC) is consistently increasing and the State of Tamil Nadu is leading in marine crab landings particularly for the blue swimming crab production in India (Fig.2). The major landing centres for BSC are located in the Palk Bay (PB) and Gulf of Mannar (GoM) areas of Ramanathapuram, Pudukkottai and Thanjavur districts of the state. BSC products form the most important internationally traded commodity from the region and contribute significantly to the livelihood of crab merchants and crab fishers of the area (Josileen et.al., 2018 unpublished).

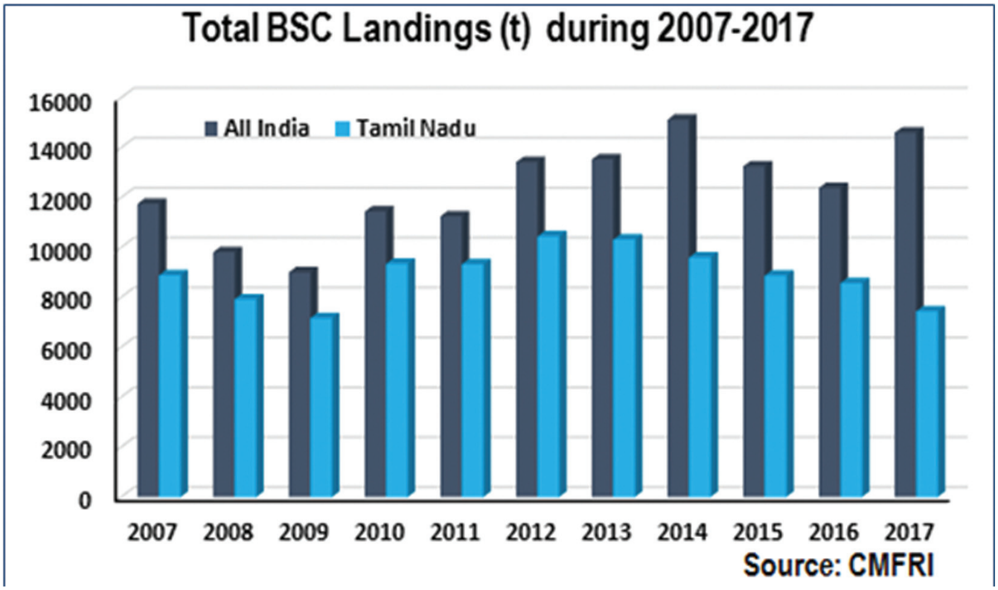


Fig. 2. Total BSC landings during 2007-2017

The overall trend of the BSC clearly shows a declining trend and it is the right time to make necessary steps to control and manage the fishing towards a sustainable fishery for the future use. Here we make an attempt to certify the fishery which is a long term process and through which all the stakeholders of the fishery would be cautious and work hand-in-hand to bring the fishery to the status of a well-managed fishery.

Fig. 3. View of a gill net landing centre at Palk Bay, Tamil Nadu

For the management of the fishery needs a thorough knowledge about the following aspects:

- Fishery and Fishing practices-Craft & gear
- Total Landings –gear wise & centre wise (10 or more years data)
- Ecology of the fishing area
- By-catch
- Market & Price structure (Value chain)
- BSC Biology & life history
  - Life Cycle the
  - Size Composition and Sex Ratio
  - Size at maturity
  - Breeding and composition of berried crabs
  - Fecundity
  - Carapace Width-Total Weight Relationship
  - Morphometric relationship
  - Food & feeding

  - Growth & growth parameters
- Maximum Sustainable Yield (MSY) - Palk Bay BSC
- Harvest strategy

Based on these information, we have to identify the strengths and weakness of the fishery and appropriate management plan should be prepared and implemented to achieve the long term goals as a well-managed fishery. In the management plan, roles of each stakeholder should be clearly envisaged and strict adherence to the rules and regulations must be ensured. A well-managed fishery not only focus on the sustenance of the fishery but perform in a wider perspective, to the triple bottom line approach- environmental, economic and social sustainability.

The strengths of the BSC fishery are as follows: regular monitoring of fishery, ecological and geographical parameters of fishing area i.e., Palk Bay, total landing of the BSC and other resources, complete life history with detailed biological parameters of the BSC from the area etc. available with published information. BSC is a fast growing species reaching 100g size within 6 months' time with a short life span of 2.5 to 3 years and mass seed production and farming of the species are proven.

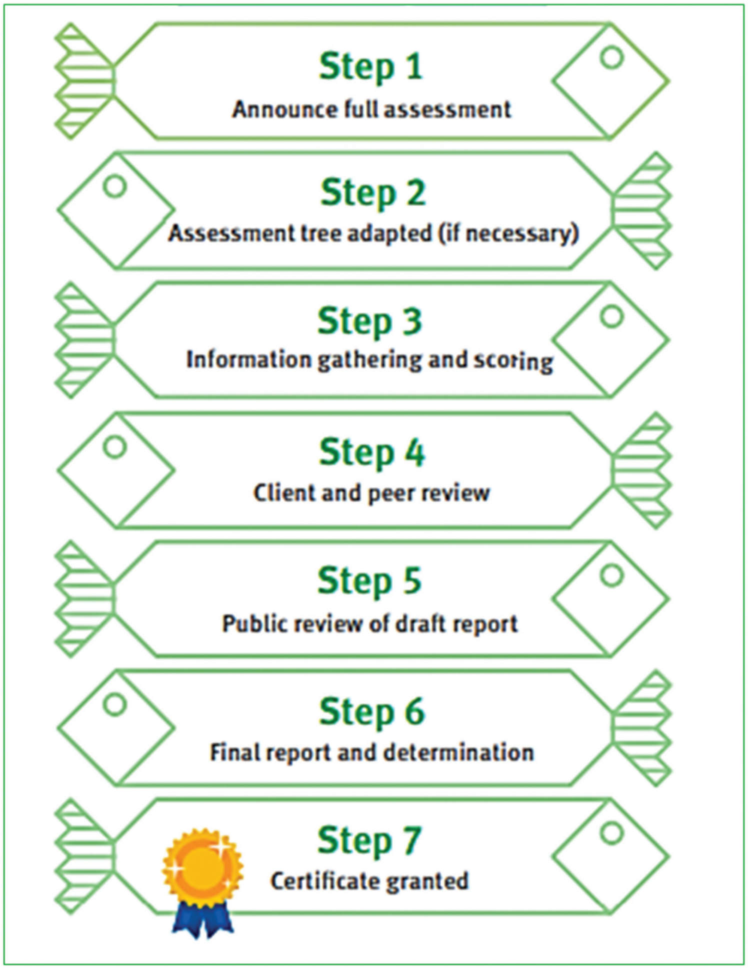
For certification purpose it is very important to select the gear and the area of fishery; for Blue Swimming Crab certification, "gill net fishery of Palk Bay" been identified. Crab gill net locally known as 'nanduvalai' is a non-destructive gear and no ETP species are caught in Nanduvalai. In Crab gill net, only Crabs are targeted; BSC is the major species caught however, minor quantities of other crabs, prawns, fishes and gastropods are also form a part of the catch. The stake holder consultations conducted in this regard gave encouraging approach by fishers and processors, which is a welcoming act. Majority of the fishers and Crab Meat Processors Association (CMPA) are ready to accept and comply the proposed management plan. The most crucial immediate steps to be implemented for promoting the fishery to the sustainable level are:

- The Minimum Legal Size (MLS) is also soon implemented through TNMFRA i.e., it will permit to land and sell/purchase crabs of size (carapace width CW) 90 mm CW and above.
- Total Ban on landing of berried females- berried crabs must be put back to the sea as early as possible.
- No trade of berried crabs - Crab processors/merchants should not buy berried crabs/ undersized crabs.

Full Assessment

Full assessment is the detailed, public, rigorous process that the certification body will follow to determine whether or not your fishery meets the MSC Fisheries Standard. The process starts when you, the fishery client, sign a contract with your certification body and they notify the MSC that your fishery is entering full assessment. The average time taken for a full assessment is 12 months and the minimum is 8 months. The length depends to some extent on your preparation as well as the nature and complexity of your fishery.

Overview of the full assessment process



Once the fishery become certified against the MSC Chain of Custody Standard, products from your MSC certified fishery can bear the MSC ecolabel on packs or menus. The blue fish label is only applied to wild fish or seafood from fisheries certified to the MSC standard, a scientific measure of sustainable fishing.

Impact

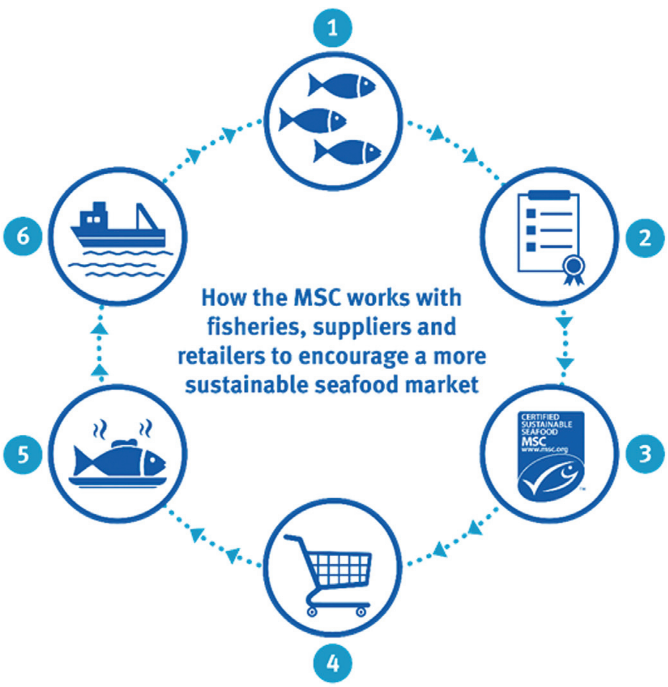
For over 20 years fisheries, scientists, consumers and industry have been part of a collective effort to make sure our oceans are fished sustainably. Since its foundation in 1997, fisheries responsible for 12% of marine catch have been certified to the MSC Fisheries Standard. Certification is helping to grow and maintain the number of sustainable fish populations. To remain certified, fisheries have so far made over 1,200 improvements to their performance and management. More than 38,000 sites, including supermarket chains, restaurants, fishmongers and hotels are now certified to sell seafood with the blue MSC label. Now, more than 25000 products are sold with the blue MSC label in the market.

A virtuous circle

When you buy a product with our blue fish label, you become part of a virtuous circle, helping to protect the productivity and health of our oceans.

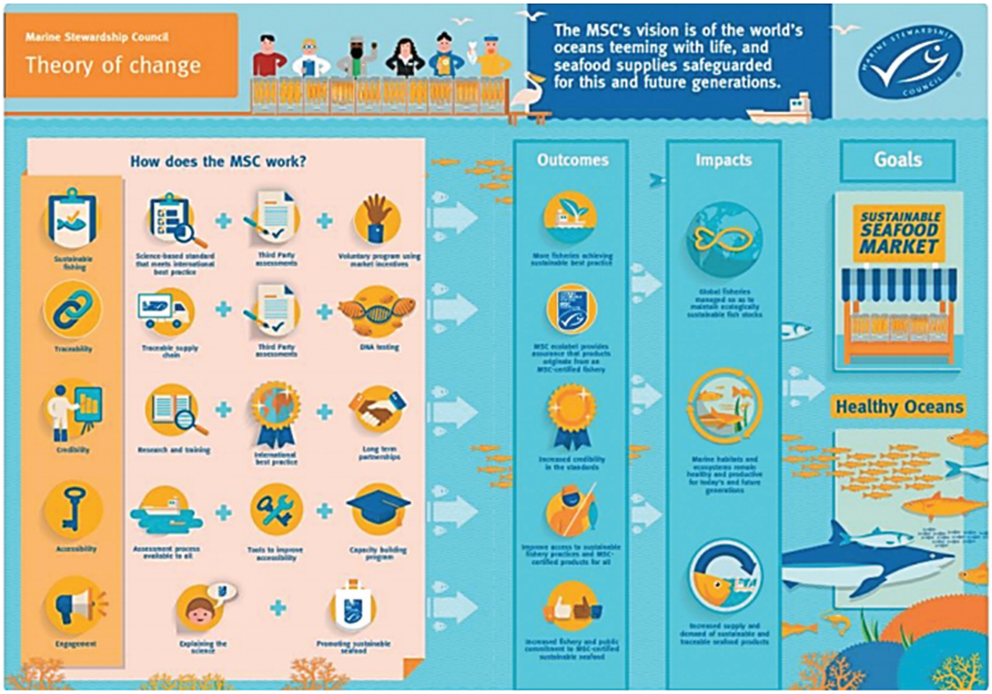
Here's how it works:

1. **Fisheries -**that meet the MSC Standard are independently certified as sustainable
2. **Retailers and restaurants-** choose MSC certified sustainable seafood
3. **A traceable supply chain-** assures consumers that only seafood from an MSC certified fishery is sold with the blue MSC label
4. **Consumers-** preferentially purchase seafood with the blue MSC label



5. **Market demand-** for MSC certified seafood increases
6. **More fisheries-** choose to improve their practices and volunteer to be assessed to the MSC Standard

MSC's theory of change describes how the program will contribute to the MSC achieving oceans teeming with life, and seafood supplies safeguarded for future.



For Further reading- visit: https://www.msc.org

CHAPTER

17

Assessing the Externalities of Marine Fish Trade in India

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Fisheries is one of the fastest growing food sector in the world economy, which provides livelihood for more than 200 million people around the globe. India, being the second largest producer of fish in the world, contributes about 5.43 percent of the world production. Fisheries sector plays a very important role in the socio – economic development of the country by providing a source of livelihood with direct employment to over one and a half million people, besides the indirect employments, contributes much to the food security and export earnings of the country as well. Eventually, there are wide-ranging variations in marine fish landings, which might have serious impacts on the economy of the country. Even though the quantity of landings is depreciating in thirteen major marine areas out of fifteen there is almost a fivefold increase in the case of India, since 1950.Over the years, the sector continues to play strategic role in food security, international trade and employment generation. Indian economy has grown consistently post-liberalization with higher purchasing power and consistent demand for diversified food products. With changing consumption pattern, emerging market forces and technological developments, the fisheries sector has assumed added importance in India with rapid transformation. The present fish production is 11.04 Mt with a contribution of 3.83 Mt from marine sector and 7.21 Mt from inland sector. The fish prices in domestic market are rising leading to issues of fish availability, accessibility and affordability. Global capture fishery production has been plateauing and has more or less stabilized at around 80 million t. (FAO, 2012a). Trend in the state of marine fish stocks shows that proportion of overexploited and fully exploited marine fish stocks are increasing with simultaneous decrease in fish stocks that are not fully exploited. Studies from five ocean basins revealed 90% decline in numbers of large predatory fishes since the advent of industrialized fishing (Myers and Worm, 2003; Worm et al., 2006). Fishing down the web effect is pervasive in world fisheries, including Indian fisheries. World per capita food fish consumption hits a record high of 20 kg per year from an average of 9.9 kg (live weight equivalent) in the 1960s to 18.4 kg in 2009. With the increasing global population, in order to maintain at least the current level of per-capita consumption of aquatic foods, an additional 23 million tonnes of fish will be required by 2020.

Marine population relies upon the great biodiversity of habitats and resources for food, materials, breeding and larval disposal environment. This interdependence is essential and maintaining a balance between them is cardinal. But the marine ecosystems are deteriorating at an alarming rate mainly due to over exploitation of species, introduction of exotic species, pollution from urban, industrial, and agricultural areas as well as habitat loss and alteration of water diversion, and excessive use of water resources. As a result, valuable marine aquatic resources are becoming increasingly susceptible to both natural and anthropogenic driven environmental changes.

Widespread impacts of human activities on the oceans continue to cause declines in species diversity and abundance. As recognition of the benefits that healthy marine ecosystems provide to people increases protecting biodiversity and the essential ecosystem services supports has become a priority for the scientific community, resource managers, and national and international policy agreements, including the Convention on Biological Diversity (CBD). Decreases in species richness or abundance can threaten ecosystem services such as fisheries or nutrient cycling, and can reduce overall ecosystem stability and resilience. These declines have been documented for numerous marine ecosystems and can sometimes lead to major shifts in food web dynamics. Many of these changes can be attributed to human impacts such as climate change, overfishing, and pollution. However, limited capacity and financial support for conservation and management necessitate that resources be directed to regions where investment could best sustain areas of high marine biodiversity and their associated ecosystem services. Overfishing, irresponsible and destructive fishing practices, and illegal, unreported and unregulated (IUU) fishing have long been recognized as leading causes that have reduced biodiversity and modified ecosystem functioning. Marine biodiversity loss is increasingly impairing the ocean's capacity to provide food, maintain water quality, and recover from perturbations. Recent studies indicate that investing to achieve sustainable levels of fishing by strengthening fisheries management, financing a reduction of excess capacity on the conventional resources and adoption of a responsible fishing regime are required to rebuild the overfished and depleted conventional fish stocks.

Marine fish capture in India

Marine fish production of India increased to 3.83 million ton in 2017 contributing 38 per cent of the total fish production. About 1, 94,490 fishing crafts of various sizes and classes are under operation in marine fisheries, consisting of 72,559 mechanized, 71,313 motorized and 50,618 non-mechanized fishing vessels. Shelf resources are subjected to high intensity of fishing pressure and

are exploited at levels close to or exceeding optimum sustainable limit. Problems of juvenile finfish mortality and bycatch discards increased with the intensification of shrimp trawling. Plateauing of catches from mid 1990s, economic and growth overfishing at several centres, and inter-sectoral conflicts in the coastal belt have highlighted the need for regulation of fishing capacity, adoption of responsible fishing practices and caution in marine capture fisheries development. Overfishing and fishing down the web effect is evident in Indian fisheries. Removal of excess fishing capacity and adoption of responsible fishing gear and practices and a conducive fisheries management regime would contribute to the long-term sustainability of the resources, minimize negative environmental impacts, protect biodiversity and facilitate rebuilding of the depleted marine fish stocks.

Species composition and Fisheries trade in India

The marine fish landings across the years had increased and the landings were estimated at 3.83 million tonnes in 2017. The total valuation of marine fish landings at the landing centre (point of first sales) was estimated at 52431 crores and that of the retail centres was found to be 78408 crores during 2017-2018. The markets had been the major driving force behind the realization of the huge value of landings. It is also important to note that the marketing efficiency was found to be quite high with the fishermen share in the consumer's rupee of 63.88 per cent. Nevertheless the producer share in the consumer's rupee has varied sizeable based on the commercial value of fish, seasons, landings source and proximity to consumption centres.The valuation of Indian fisheries vis a vis Landings – Major species is given in Table 1.Although the Oil sardines registered the highest landings, they contribute 8.87 per cent of value of share in the landings. Due to reduced share of the Threadfin breams landings in 2017 their share in value came to a low of 4.13 per cent.

Table 1. Species wise share in Landings (in per cent)

Species	Landings (tonnes)	Share (%)
Oil sardine	338,029	8.87
Indian mackerel	295,246	7.75
RIBBON FISHES	240,502	6.31
Other sardines	236,668	6.21
Penaeid prawns	211,749	5.56
Non-penaeid prawns	202,216	5.31
Other perches	194,118	5.10
Threadfin breams	157,170	4.13

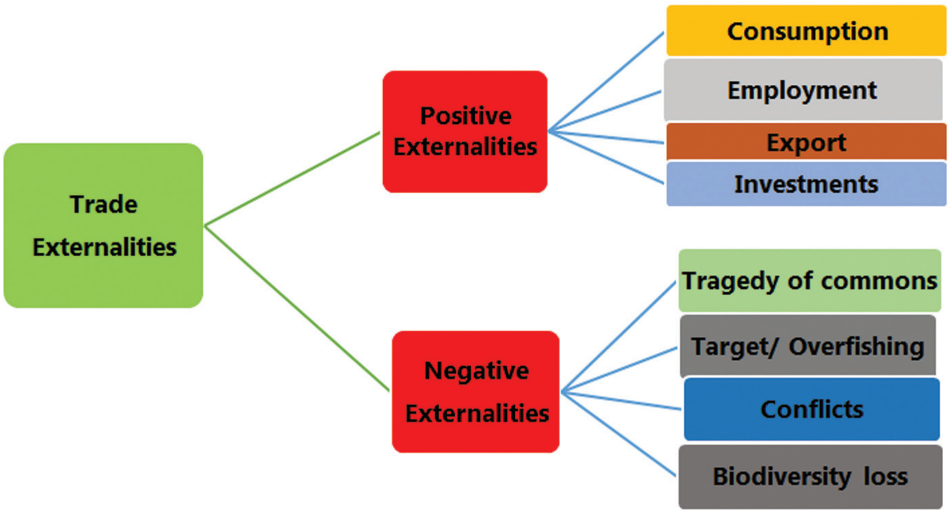
Markets had been the major drivers for the fisheries production system channeling the fish landed/ produced in realizing the value. The functional growth of the markets in terms of its size, designs, infrastructure, realm of functioning, degrees of competition, nature and volume of transactions, periodicity played a major role in the realization of such high value at the different constituents of the value chain. With the changing economic scenario and fish being a vital commodity being traded at the domestic and international markets, importance of fish in the food and nutritional security, employment generation and income earning the marketing of fish plays a very important role in the fishing business. The marketing system also poses a scope for more institutional interventions .The current level of marketing couldn't ensure high quality of fish on account of unhygienic practices and doesn't offer much option for the consumers. The fish needs to reach the different nuke and corners of the country for which the market potential is to estimate .It is important to note that the fish consumption is restricted mostly within the near vicinity of less than 50 km of the production centers. There if found to be movement of fish across the different districts/ states which could solve the seasonality issues of fish in the country. Nevertheless the demand patterns have improved much and the increased fish consumption was found mostly among the existing fish consumers rather than adding new consumers into the fish consuming population. It is estimated that 56 per cent of the population eat fish with a per capita consumption of 4kg/ annum.

The technological innovations, improvements in the infrastructure over the years the marine fish marketing is grappled with numerous bottlenecks at the production, distribution and consumption centres. These had been due to the inelastic nature of supply and distress sale, seasonality of landings during peak and lean seasons, huge amount of by catch/ discards due to non-efficient marketing systems and latent markets, distress sales due to the geographical differentiation of the production and consumption centre, indebtedness to the middlemen(traders), lack of institutional and policy support, Inadequate cold chain facilities, lack of value addition, poor marketing infrastructure ,improper fish handling, seasonal variations in demand & supply, unhygienic handling and poor quality control, unethical trade practices and highly localized preferences.

Amidst of these now according to fishers, fishing activity substantially evolved in the area with time, expanding towards deeper grounds and towards areas more distant from the coast. The maximum amount of catch ever caught and the weight of the largest species ever captured inversely declined with time. The fish marketing and trade are crucially affected by the depletion of fishing grounds where depletion occurred. The ecological changes of marine biodiversity during the last half of the century cause the decline of commercially important fish .Declines and extirpations were in line with available quantitative evaluations from stock assessments and international conventions, and were likely linked to fishing impacts. These changes were likely related to trophic cascades due to fishing and due to climate change effects. The species composition of depletions, local extinctions and proliferations showed differences by region suggesting that regional dynamics are important when analyzing biodiversity changes and there by fish trade. *However the WTO fisheries negotiations are often said to provide the single greatest opportunity for the marine fishery. The focus is on cutting the subsidies that allow for the overexploitation of fisheries, and thus on safeguarding the resource itself and the significant economic and livelihood gains. In addition, the phase-out of destructive subsidies would open up the possibility of re-channeling subsidies into carefully crafted management schemes, as well as into conservation initiatives such as Marine Protected Areas. As such, the benefits for ocean biodiversity as a whole could be rich and generate positive outcomes for generations to come.*

Externalities in Fish trade

An externality is a positive or negative consequence of an activity experienced by unrelated third parties. Externality occurs in an economy when the production or consumption of a specific good impacts a third party that is not directly related to the specific production or consumption. In fisheries, externalities are defined as every external effect caused by individual fishers but not included in their accounting system. Externally imposed benefit of trade is a positive externality and those imposed cost is a negative externality. Externalities in fish trade are in evitable. There are positive as well as negative externalities exists for fish trade. Fish consumption, employment, export and trade are considered as the positive externalities. of fishers whereas MSY, sustainability, target fishing, over fishing etc. are noted as the common negative externalities.



Fish has become an indispensable part in the food basket of the as it is considered as a healthy food which is rich in edible protein. It is considered as the poor man's protein and it is a source of cheap and nutritious food assuring food security. Due to the increased fish trade people consume more fish despite of the price. During the early 70's fish consumption pattern stood at 15kg per annum were it declined, but the reality is that at each household there is at least one meal with fish every day. About 80-85 percent of India's population are non – vegetarians and with the shift in lifestyle and upsurge in the cost of meat, the fish intake in is flourishing and also the fish consumption in rural areas is higher than the urban area. The high fish consumption and trade imparts fish investments in the fisheries sector showing the best positive externality in fish trade. The increased investments thereby enhance the sustainability of the trade promoting high employment opportunities and also export. Kerala is considered as the greatest fish consuming state in the country and the average per capita fish consumption is 27-30 kg. The hike in fish consumption is mainly associated with the upsurge in income, increasing health consciousness and changing life style of the people. While considering the domestic fish market which is managed not only by the purchasing power of the consumers but also mostly by their taste and preferences.

Fisheries sector contributes significantly to the national economy while providing livelihood to approximately 14.49 million people in the country. It has been recognised as a powerful income and an employment generator as it stimulates growth of a number of subsidiary industries and is a source of cheap and nutritious food besides being a source of foreign exchange earner. Among the nine coastal states of India, Kerala holds the second position in terms of fisher folk population. The fisheries sector in India has undergone rapid changes over the last six decades to develop from a sustenance fishing to the status of a multi-crore fishing industry. The Indian economy has relies sufficiently on fishing for subsistence, livelihood and employment. Within Kerala, consumption of fish is four times the national average and the state produces 16.6% of the shares of India's total marine exports, the second largest in the country. The fisheries sector offer promising future for the livelihood, employment and food security. There also exists a wide competition among the buyers for fish. It was noticed that for certain species like sardine, mackerel, seer fish, squid, cuttle fish and ribbon fish the domestic market price is higher when compared to the export market price. Even though the export earns us a valuable income, the diversification of fish and fishery from local communities thus there is a prevailing question on the availability and affordability of fishes in the domestic market.

Fishing externalities are commonly negative and occur when fishers can freely enter and capture a resource, and where a voluntary agreement of co-operation does not exist; in these cases, resource users do not consider the external effects impose on others. Tragedy of commons, target fishing, conflicts and biodiversity loss are considered as the major negative fish trade externalities. Too many boats running for few fishes create a high negative externality and thereby increasing the chance of tragedy of commons. The increased target fishing and over fishing also promotes the tragedy of commons and thereby biodiversity loss. Due to the increased fish trade majority of the fish trade is with the drawlers despite of others creates conflicts among fishers. The entry of new vessels reduces stock availability and hence the harvesting costs of others. Fishers do not consider these costs because they only take into account their private fishing trip costs (internal); ignoring the external costs imposed to others by stock reduction. Vessel aggregation on the fishing grounds increases marginal catch costs. Occurrence of such externalities depends on the extension of the fishing ground and the stock magnitude. Fishing effort will not be perfectly allocated in space (*e.g.*, over the greatest resource concentrations) and time (*e.g.*, they would wait to have access to a limited fishing ground). This externality is commonly seen in sedentary species with patchy distribution, where the exploiting strategy tends to sequentially deplete the most profitable beds.

Moreover technological externalities also arise when the fishing gear changes the population structure dynamics of the target species and associated by catch, imposing negative effects to other fishers, and affecting the abundance of incidental species which might constitute the target of other fisheries. Two types of technological externalities could be distinguished:

(i) Sequential externalities: Occur when artisanal and industrial fleets exploit different components of the population structure of the same species, thus affecting each other. Artisanal vessels tend to apply their fishing effort close to the coastal zone where juveniles inhabit, while the industrial fleet generally operates in deeper waters, exploiting the adult component of a stock. Thus, a substantial increase in fishing effort of the artisanal fleet would cause recruitment overfishing and a decrease in stock availability for the industrial fleet in subsequent periods, *i.e.*, a negative externality for the industrial fleet. Analogously, an increase in fishing effort of the industrial fleet will diminish the spawning stock, affecting subsequent recruitment and thus stock availability for the artisanal fleet.

(ii) Incidental externalities: These arise in technological interdependent fisheries, when fleets use non-discriminatory fishing gears, *e.g.*, a by catch in fishery A diminishes the abundance of those species that constitute the target for fishery B. The non-accounted negative external effect for fishers belonging to fishery A constitutes an incidental externality. It is commonly observed in shrimp and demersal fisheries, where the shrimp fishery generates incidental catches of demersal species, a non-accounted negative effect that generates and externality to the demersal fishing fleet.

Overcapacity

Overcapacity or overcapitalization can be defined as a long term problem in a fishery whereby the size of the fishing fleet, its harvesting ability or fishing power exceeds what is necessary to harvest an optimum yield. Since most fisheries are fully exploited or overexploited, existing fishing capacity exceeds what is necessary to harvest the maximum sustainable yield (MSY) and/or maximum economic (MEY). Optimum harvesting levels are set as part of the management objectives for a given fishery. For instance, food security objectives are best met at MSY, whereas profitability and economic efficiency objectives are met at MEY. The adoption of United Nation Convention Law of the Sea (UNCLOS) ascertained the “level which can produce the Maximum Sustainable Yield (MSY) as qualified by relevant ecological and socioeconomic factors”. Nonetheless, MSY and its proxies and variants are still enshrined as quantitative management benchmarks in national, regional, and global legal fishery frameworks. Although as part of the Convention, the norm is fully binding, its qualification by unspecified “relevant ecological and socioeconomic factors” allows for flexible interpretation and implementation, such that the mandatory norm is still loosely applied in most countries .The UNCLOS provides also that States should take measures “with a view to maintaining or restoring populations of such associated or dependent species above levels at which their reproduction may become seriously threatened”. While not referring to MSY, this requirement still implies de facto that non-target species should not be overfished either.

Marine debris and pollutants

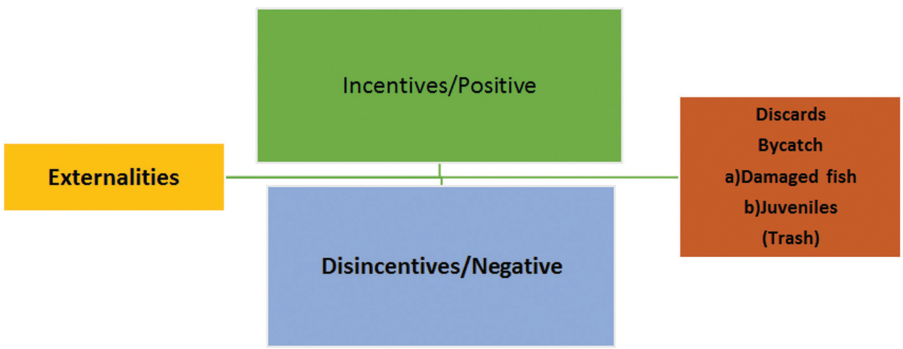
Abandoned, lost or otherwise discarded fishing gear (ALDFG), generally known as ‘derelict fishing gear’ and related marine debris of plastic origin are recognized as a critical problem in the marine environment and for living marine resources in terms of the long-term sustainability of fish stocks and biodiversity conservation, due to ghost fishing and habitat loss and impact on endangered species such as marine mammals. Approaches to minimize plastic debris due to abandoned, lost or discarded fishing gear include (i) use twines, ropes, netting, connectors and shackles of correct specifications and breaking strength, in fishing gear fabrication; (ii) introduction of a system of marking fishing gears and procedures for reporting of lost fishing gears and their retrieval; and (iii) compliance of International Convention for the Prevention of Pollution from Ships (MARPOL) regulations which prohibits at sea disposal of plastics and other synthetic materials. Pollution of the marine environment by ships of all types, in terms of garbage, waste oil and oily mixtures and engine emissions is strictly controlled by the International Convention for the Prevention of Pollution from Ships (MARPOL). The discharge of oily mixtures having oil content above 15 ppm, into the sea, is prohibited and all vessels over 400 tons are required to be fitted with oil filtering/separating equipment to comply with this regulation.

Economic externalities of fishing operations

Fisheries over the years evolved from subsistence fishing towards a capital intensive enterprise. There has been structural transformation in the fishing fleet with motorization and mechanization. The current scenario of marine fisheries in terms of fishing fleets clearly indicates a situation “too many boats chasing too few fishes”. Due to the tragedy of commons in operation, increasing fleet size as well as costs of fishing and the decreasing catch per unit efforts, the fishing operations have taken a toll. The mechanized sector is venturing into multiday fishing which negate the losses of fishing cost. Sizeable amount of low value fishes are landed across the landing centres on account of targeted fishing. Low value fishes include juveniles, bycatch, trash fishes and discards and it is estimated that around 30% of the mechanized landings constitute low value fishes which has a huge untapped economic value. Economic loss due to low value catch could be reduced by implementing mesh-size regulations to avoid juvenile catch, prevent discards and utilizing bycatch. Appropriate utilization strategies are to be developed with respect to discards, regulating multiday fishing operations or innovative measures may be adopted to land the catches on frequent intervals. There exists a huge consumer demand on account of the escalating domestic market prices of fish.

Externalities in trawl operations due to low value fishes

There exist positive and negative externalities in the trawl fishing operations with reference to low value fishes. Discards are thrown back due to non-realization at the landing centers. Bycatch that includes trash fish, damaged fish and juveniles are brought back to the landing centres because of its economic utilities. Thus the low value landing possesses considerable incentives (positive externalities) and disincentives (negative externalities). The positive and negative externalities have been calculated to find net economic losses due to low value fish catch. Damaged fishes are marketable but at very low price. Juveniles of many commercial fishes are being sold at less than '10 per kg. If it is harvested at the table size or with superior quality or caught in proper gears, it may fetch a higher price. So the negative externality was calculated with regard to discards, damaged fish and juveniles. Trash fishes, which were discarded earlier and fetching good market price now are being used for fish meal which has generated an incentive. Based on the incentives and disincentives, the net economic loss/gain by trawl fishing and the landings of low value fishes are worked out.



Technologies to reduce biodiversity loss

Some of the fishing technologies to reduce by catch and discards include the

Gillnetting

By catch in drift gill nets may include marine mammals, sea turtles and sea birds, in addition to non-targeted fish species. Optimization of gill net mesh size and hanging coefficient according to the target species and size group and judicious deployment of gill net in terms of fishing ground, fishing depth and season in order to minimize the gear interaction with the non-targeted species

are important bycatch mitigation measures for gill net fisheries. Recent innovations have attempted to make the gill nets detectable by marine mammals having echolocation abilities, using acoustic pingers and specially treated netting. Lost gill nets continue to gill and entangle fish and other marine organisms which is generally termed ghost fishing. One approach to minimize ghost fishing by lost gill nets, is to use biodegradable natural fiber twines or time release elements to connect the netting to floats. When floats are separated due to the disintegration of these links, the gill nets lose their fishing attitude and consequently lose the ability for ghost fishing. Another approach to prevent ghost fishing is to locate and retrieve lost fishing gear.

Hook and line fishing

Optimized hook design and size and selection of bait type and bait size appropriate for the target species and size class, proper choice of fishing ground, depth and time of fishing are approaches for mitigation of bycatch issues in hook and line fisheries and minimize gear interaction with other species. Interaction with sea birds during long line operation are minimized using dyed bait, deploying bird scaring devices (streamers) in the area where bait is set and by using sub- surface setting chutes for deployment of branch lines. Sub-surface setting chutes, blue-dyed bait, weighted baits and side-sets were reported to have reduced the bycatch of seabirds in the longline fisheries.

Reducing bottom impacts of towed gears

Bottom trawling caused direct and indirect impacts on marine environment and benthic communities .Approaches to minimize environmental impacts of bottom trawling such as semi-pelagic trawl systems, benthic release panels and ground gear modifications in bottom trawls, otter board designs with narrower footprint, smart trawling techniques and low impact and fuel efficient (LIFE) fishing have been discussed by a numerous studies. Semi-pelagic trawls have comparatively low impact on the benthic biota, as it operates a little distance above the sea bottom. Use of lighter ground gear and use of rollers, wheels and bobbins with their axes perpendicular to the direction of towing has been known to reduce bottom impact during trawling, without significantly affecting the catch rates. High aspect ratio vertically cambered otter boards typically have lower angle of attack and narrower footprint compared to traditional otter boards .The area of seabed affected by high aspect ratio otter boards is typically 40% of the area affected by low aspect ratio otter boards with similar board area. Use of shorter and lighter bridles and sweeps, where herding effect is not important in the catching process, could reduce the impact on seabed. Smart trawling systems have been under development in which the distance of otter boards and ground gear from the sea bed is constantly and automatically measured and adjusted by special instrumentation.

Capture based aquaculture

Capture based aquaculture (CBA) is another alternative method to cope up with the externalities of fish trade. Since there occurs high fish trade and consumption capture based aquaculture will enable to increase those positive externalities to a great extent. CBA is an economic activity that is anticipated to expand in the short term, and is very likely to continue into the long term for many species. CBA is practiced because it has become necessary or desirable as a livelihood, as an alternative means of controlling access to fishery resources, to meet market demand and, if practiced properly, to enhance yield.CBA is typically practiced with high value species, often for export or luxury markets, rather than inexpensive food alternatives for local use. One other factor that makes CBA appealing is the belief that taking fishes or invertebrates when they are small and young and placing them into captivity for feeding and protection from predators reduces their natural mortality. In this way, the practice is widely assumed to increase productivity by enhancing survivorship relative to natural levels at a given size or age. Moreover, the degree of bycatch and discards and the mortalities of wild seeds during and after capture (i.e. from capture and during culture) can be extremely high, factors rarely considered when examining the culture of such species. As the demand for seafood grows and over-fishing and competition for fishery resources increase, CBA is inevitable and must be addressed directly to ensure sustainable practices.

Value Addition

The fishery sector is in its hike in the fish trade and consumption however large quantities of fishes are discarded because of size, species, uneconomic to preserve etc. It has been estimated that the global amount of discard of by-catches is in the range of 17-39 million tons/year with an average of 27 million tons/year. Factors discouraging the landing of the by-catch are the low market value of the material, the size and species composition, the lack of suitable refrigerated storage space on-board and the possible reduction in marketing efficiency. Consumption of fish may be greatly increased there by raising the positive externalities of fish trade by making better use of the existing catch. Due to lack of infrastructural facilities like ice plants, landing facilities etc. the quality of the fish is downgraded particularly in developing countries leading to their use as aquaculture feed. Through improvement in infrastructure facilities, the quality of the landings can be upgraded for direct human consumption. The up gradation of these species may be achieved by use of improved handling and processing techniques on one hand and developing different products by the preparation of value added products on the other hand. The seafood industry in many countries is undergoing a rapid transformation to process more ready-to-cook and ready-to-eat food in convenient packs. Indian seafood industry, by and large, still remains a supplier of raw materials to the pre-processors in foreign countries and 90 per cent of it goes in bulk packs, which is the prime reason for lower unit value realization. So interventions should be made to promote the production of value added fish products to increase the consumption rate as well as the export rate and thereby decreasing the negative externalities such as over fishing and biodiversity loss.

Conclusion

Fisheries management is a complex process that requires the integration of resource biology and ecology, with socio-economic and institutional factors affecting the behavior of fishers and policy makers. The purpose of this is to aid a decision-making to achieve a sustainable development of the activity, by analyzing the measure to improve the positive externalities and to reduce the negative externalities in fish trade, so that future generations can also benefit from the resource .Consumption studies show that fish consumption has increased to its peak and consumers are pay more money than producers get. The development of a real time fish market grid to act as a decision support system would ensure fish market and price information dissemination about availability, accessibility and affordability of fish. Government interventions should be made in regulating fish exports and substituting exports with increased value added fish products. Hence the employment opportunities on the same could also be enhanced. Moreover the investments in the post harvesting sector should be increased to reduce the spoilage losses. Governmental measures for the manufacturing of boats, registration, color codes etc. could reduce the tragedy of commons. Also earmarking fishermen as the primary stakeholders are one of the best method to reduce conflicts among the fishers. Sustainability has been far more difficult to achieve that is commonly thought almost 70% of the individual fish stocks around the world are fully to heavily exploited, overexploited or depleted .Indeed, depressed yields, coupled with a rise in demand and prices, determined a systematic decreasing trend in catch rates and global landings. Conventional management measures, such as minimum size limits and reductions in catch or in fishing effort, have been used to promote stock rebuilding by reducing fishing mortality and increasing survival of spawning stocks.

The Adoption of ecosystem based fisheries management which incorporates responsible fishing practices along with strict regulation of fishing capacity at sustainable levels and establishment of marine protected areas (MPAs) would facilitate protection and restoration of biodiversity and enhance the resilience of the fish stocks and ecosystem services. A wide range of proven technologies and procedures are readily available for minimizing the direct and indirect impacts of harvesting operations on biodiversity. Adoption of such technologies may only be successful with the active involvement of stakeholders in the process, supported by a system of incentives and disincentives and training, under a participatory management regime. BRDs and TEDs need to be adopted and enforced legally, under a participatory management regime, in order protect the biodiversity and prevent trawling. Ecofriendly practices are to be promoted in purse seining, gillnetting, lining and trap operations, to minimize the impact on non-target species and environment. Technologies and procedures for minimization of GHG emissions from the fishing fleet need to be promoted through legislation, stakeholder education and training. Procedures for minimization of plastic waste originating from abandoned, lost or discarded fishing gear, need to be adopted. Strict regulations for safe disposal of garbage, oil, oily mixtures and other residues originating from fishing vessels operations, need to be promoted and implemented, for protecting the health of fisheries environment.

CHAPTER

18

Economic valuation of ecosystem goods and services with special reference to estuarine wetlands

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Economic valuation of biodiversity is performed for three important reasons *viz*., (i) to facilitate cost-benefit analysis, (ii) to integrate with the system of national accounts i.e. 'green accounting' and (iii) for proper pricing of biological resources. Cost-benefit analysis of investments and policies, that incorporate environmental costs and benefits, are essential to enable planners and policy makers to choose the investment that would bring in maximum net benefits to the society. Environmental accounting adjusts the standard gross domestic product (GDP) measure to take into account any depreciation in the environmental base of the economy. In the absence of markets for the biodiversity or the services, valuation of loss in biological diversity is necessary to maintain a balance between conservation and economic development.

The biological diversity, irrespective of the type of ecosystems, are largely in danger due to constant pressures exerted on them for economic development. Therefore, economic valuation helps to place a value on changes in biodiversity and paves way to introduce incentives for conservation. Valuation does not entail measuring the economic value of biodiversity as such (Pearce and Moran, 1994). Instead, valuation focusses on the economic values of goods and services generated by biodiversity and functions. Economic valuation recognizes that individuals may assign value for different reasons and not only for the immediate benefits of commercial exploitation of resources. Economics generally assign value on the basis of direct or indirect trade-offs, that is, actions that show people revealing their willingness to pay for goods and services by exchanging them on markets. Environmental economics has extended demand theory to goods and services that are not traded in markets, including most ecosystem services. Considerable efforts have been made by economists to develop methods that can also elicit hidden value of non-marketed natural resources.

Kahn et al. defines ecological services as "functions that ecosystems perform, that provide the basis for all ecological and economic activity, and include services like carbon sequestration, nitrogen fixation, hydrological cycles, nutrient cycles, biodiversity, production of oxygen, maintenance of global climate, soil formation and primary productivity". The economic valuation of non-use benefits is difficult, but crucial since these contribute substantially to the total value of biological diversity. Valuation usually attempts to measure the value of ecosystem services in monetary terms in order to provide a common metric in which to express the benefits of the variety of services provided by ecosystems.

Importance of valuing coasts and estuaries

The ocean is abound with wealth of resources which man has been exploiting since ages for food, medicines and products of industrial applications. The marine and coastal ecosystems including the estuarine wetlands are priceless assets that contribute significantly to human survival, well-being and quality of life. However, humans generally underestimate the importance and value of these ecosystems and often ignore the anthropogenic impacts on these sensitive ecosystems. Our coasts and estuaries are seen as bottomless pits for dumping of municipal and industrial wastes and as a result, many of our coastal and estuarine wetlands have become highly polluted and uncongenial for the survival of biota. This also affects the livelihood of coastal people who are dependent solely on these ecosystems.

Estuaries since long have been focal points for human activity as these formed important areas for the harvest of food and fibre. Due to varied uses and anthropogenic interferences, most of the estuaries are under serious threat. The increasing population and the commercial developments are exerting tremendous pressure on the estuaries which calls for creating a balance between conservation and development.

Coasts and estuaries have both direct and indirect effects on our physical, emotional and personal well-being. Therefore, protection and restoration of these coastal areas will affect the personal and economic well-being of people. Economic well-being means different things to different people. For some, it may be having a good income, while for some it may mean happiness that sometimes comes at a financial cost, while for public officials, economic well-being may be economic activities or development programmes that benefit a society. Therefore, the quality of coastal and estuarine areas and access to these areas influence all of these measures of economic well-being.

Total Economic Value (TEV)

Value is a part of everyday life and ranges from spiritual value to religious and moral values. For economists, the definition of value is much narrower. Economic value is the quantification of the resource use for improvement of the economic well-being of a person or society. The framework commonly used for describing different types of economic value with regard to natural resources is the 'Total Economic Value' (TEV). This framework encompasses use values and non-use values. The use values are again categorised into direct use values and indirect use values.

Direct use value: Direct use value is the value we place on goods and services that we use directly, e.g. timber, firewood, fisheries, recreation etc. They involve commercial, subsistence, leisure or other activities associated with a resource.

Indirect use value: The coasts and estuaries also provides many goods and services that we do not use directly; but they become instrumental or support the production of goods that we use. For example, the estuarine wetlands provide a good nursery ground for many commercially important fishes and shellfishes that are consumed. Also, seaweeds, seagrass and mangrove vegetation draws carbon from the atmosphere and sequester in their biomass and marsh soils, reducing the effect of greenhouse gases. While these functions have long been recognized, precise field experimentation has often been lacking to show more precisely the relationships between ecosystem functions and the services they generate.

Non-use values: Many people value the coastal areas and estuarine wetlands even if they are living far away from the coasts or even if they never plan to visit or use the goods and services provided to these ecosystems. They may value in such a way they may be willing to pay in order to protect the coast and its inhabitants. This non-use value is called the '**existence value**' because these people value the ecosystem goods and services because they just know that these goods and services exist (birds, otters, mangroves, whales, dolphins etc.). The existence value are derived neither from the current direct or indirect use of the environment. Some people may also be willing to pay so that they have an opportunity in future to enjoy the coast and its services; such a value is called an '**option value**'. While some people may be willing to pay to protect and preserve the coasts and estuaries for future generations which is called the '**bequest value**'. Of all the categories, existence or passive value is most complex in terms of quantification and its role in decision-making. Yet, it is a type of economic value that is important in defining both national and global biodiversity management priorities.

The term 'value' is the amount society benefits from something beyond what it costs the society to make it or protect it. Thus the difference between the maximum that people would be willing to pay for something and the cost of providing the same is what the economists call 'value'. Many coastal activities are available at little or no cost, especially to the local coastal communities/users, while the non-residents/tourists have to pay to travel and enjoy the coastal area benefits. Thus the local users usually enjoy the greatest economic benefit from the provisional coastal goods and services. In coastal areas, generally attention is paid to the services that produce marketable goods; while services like bird watching or leisure visits is not quantified from an economic perspective.

Ecosystem goods and services provided by estuaries

Estuaries are highly dynamic ecosystems as they are the areas of confluence of sea and the river. These ecosystems are well known for their complex hydrodynamic and nutrient fluxes that result from the intermixing of saline and freshwater. This intermixing creates salinity gradients which allows the survival of wide range of flora and fauna. The medium to low saline conditions in estuaries support the growth of specialized plants called mangroves which have specialized characteristic features for salt-tolerance. Some of the common mangrove species found along the Indian coast include *Avicennia marina, Avicennia officinalis, Sonneratia alba, Rhizophora mucronata, Bruguiera cylindrica, Bruguiera sexangula, Excoecaria agallocha, Aegiceras corniculatum* and *Acanthus ilicifolius*. In addition to these, there are also many mangrove associates. The mangrove habitat is highly productive and provides a good nursery ground for numerous fauna. Estuaries are also home to many fauna including finfishes, shrimps and oysters, and their prey organisms.

Ecosystem goods and services as categorised by the Millennium Ecosystem Assessment

Provisioning	**Regulating**	**Cultural**
Goods produced or provided by ecosystems	*Benefits obtained from regulation of ecosystem processes*	*Non-material benefits from ecosystems*
• Freshwater • Food • Firewood • Genetic resources	• Flood regulation • Climate regulation • Disease regulation	• Educational • Recreational • Aesthetic • Spiritual • Inspirational
	Supporting	
Services necessary for production of other ecosystem services		
• Nutrient cycling	• Primary production	• Soil formation

The physical transport of sediments and nutrients results in unique geophysical features such as wetlands, lagoons, mud flats and sand bars which offers habitat for wide range of organisms. The mud flats which are rich in polychaetes and other benthic organisms are preferred habitats for many avian fauna.

The estuaries which are characterised by diverse geophysical features and the presence of wide range of flora and fauna provides a mixture of goods and services useful to mankind. An ecosystem service, by definition, supports 'the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfil human life' (Daily, 1997). Ecosystem goods and services occur at different scales, from local and regional levels to global levels. While control of soil erosion, flood control, nutrient cycling, waste regulation and pollination occur at local and regional scales, carbon sequestration and climate regulation occur at the global scale (DeGroot *et al*., 2002; Heal *et al*., 2005).

The ecosystem goods are the products that are available from natural systems for human use (DeGroot *et al*., 2002). The three important ecosystem services are provisioning, regulating and cultural services. However, the Millennium Ecosystem Assessment classification introduced one more type of service called the 'supporting services' which comprises of primary production, nutrient cycling and soil formation which are all necessary for the other ecosystem services *viz*., provisioning, regulating and cultural services.

Provisioning services

The estuaries provide a number of natural resources and raw materials which we essentially require and value. It includes mainly food like the edible plants, fishes, shrimps, oysters etc. as well as arable land for cultivation and grazing land for domestic animals. Worldwide estuaries are also known to provide raw materials such as lumber, fuel wood and organic matter for building as well as supplying fuel and energy (Semesi, 1998; Barbier, 2000). The estuaries also provide medicinal plants and extracts which can be used for pest and disease control. Provisioning services of estuaries also include supply of potable water and they are also medium of transportation of materials.

Provisioning services provided by estuaries

Services	Sources/Avenues
Food	Fishing, crops, grazing, aquaculture
Water	Potable water, provision for irrigation and industrial use, as medium for transportation of materials
Medicinal plants	Estuarine flora as sources of medicines and pest-control chemicals
Genetic resources	Variety of gene pools in fishes
Ornamental resources	Dried grasses, shells used as curios
Raw materials	Plant fibres, oils and dyes for building and fodder and fertilizer

Regulating services

Regulating services include regulation of climate, gas regulation, and protection from natural calamities, control of pollution and control of soil erosion. The biochemical processes in estuaries also helps in the detoxification of anthropogenic wastes generated by coastal urbanisation. The vegetation, particularly the mangroves help in control of floods as well as aid in preventing soil erosion. Estuaries can also regulate the local climatic conditions which may moderate climate gradients for people living near the coast (Johnston *et al*., 2002).

Regulating services provided by estuaries

Services	Sources/Avenues
Climate regulation	Regulation of hydrological cycle, regulation of local and global energy balance
Gas regulation	Regulation of chemical composition of atmosphere and oceans
Protection from natural calamities	Control of floods, protection from cyclonic storms
Control of erosion	Prevention of soil loss
Control of pollution	Detoxification, water purification, carbon sequestration

Cultural services

Cultural services rendered by estuaries include recreation which is measurable by the number of people using estuaries for a variety of recreational purposes (Farber, 1988). The economic valuation of such services reflect economic concepts such as willingness to pay for the recreation or willingness to accept compensation for its loss. The aesthetic value can be better understood by people's preference for proximity to the estuary. It is easier to directly measure the aesthetic value through housing market price premiums for location (Smith *et al*., 1991). The estuaries are excellent place for education and research. The estuarine wetland is a learning arena for people of all age groups on diverse areas including the dynamics in physical processes, dynamics in biological processes, biological diversity etc.

Cultural services provided by estuaries

Services	Sources/Avenues
Recreation	Eco-tourism, bird watching, leisure beach visits, game fishing etc.
Education	Ideal platform/centre for learning the physical and biological processes including soil erosion, formation of sand bars, mud flats; biological diversity including mangroves, fishes, mammals and avifauna.
Aesthetic	Wetlands add value to the houses constructed alongside.
Historic	Use of estuaries as motifs in paintings, books, folklore etc; natural features with religious or historic values

Supporting services

Although supporting services do not provide direct services themselves, it is necessary for the production of other three services namely provisioning, regulating and cultural services. The supporting services include habitat which serves as a breeding and nursery ground for large number of species of finfishes, shell fishes and other invertebrates. It helps to enhance the net primary productivity and helps in the recharge of aquifers. Supporting services also encompass soil formation including accumulation of organic matter, formation of sand bars and mud flats. Supporting services also ensures species interactions, pollination and biological control of pests and diseases.

Supporting services provided by estuaries

Services	Sources/Avenues
Habitat	Spawning and nursery ground for many species of finfishes, shell fishes and other invertebrates; refuge for both resident and migratory species.
Hydrological cycle	Helps in the recharge of aquifers,
Nutrient cycling	Enhanced net primary productivity
Soil formation	Capture of sediments, substrate formation, accumulation of organic matter, formation of sand bars, mud flats etc.
Biological regulation	Species interactions, biological control of insect pests and diseases, pollination in plants.

An understanding of the links between ecosystem services and functions is important in the management of estuarine ecosystems and the delivery of ecosystem services. The ultimate goal would be to sustain the flow of services in a fair and sustainable manner, taking into consideration the complex interactions within the ecosystems, between the humans and their supporting ecosystems (Farber *et al*., 2006). Any change in ecosystems may lead to changes in mix of services through changes in ecosystem processes (Palmer *et al.*, 2004). For example, the level of some services may decrease while the level of other services may increase. If dredging is done to increase the width of water way for transportation, it may on the other hand reduce the aesthetic beauty of the ecosystem. Similarly, increasing the mangrove plantations for combating the natural calamities and soil erosion may reduce the fisheries habitats. Therefore any development plans in estuaries essentially involves trade-offs between competing ecosystem services over time. It is necessary to characterize and measure the changes in service flows when we contemplate a development or a restoration project.

Some of the methods used for valuation

The Contingent Valuation Method (CVM)

Valuation of biodiversity and ecosystem services is riddled with many challenges, mainly due to the non-market nature of many of the goods and services. Under these circumstances, CVM stands out as one of the most appropriate methods and is used widely across the globe. The National Oceanic and Atmospheric Administration (NOAA) panel of the United States after evaluation says that "CVM studies or the application of CVM method can produce estimates reliable enough to be the starting point of a judicial process of damage assessment, including lost passive values" (Arrow *et al*., 1993). Pearce and Moran (1994) believe that CVM is the only means available for valuation of non-use values and the estimates obtained from CVM surveys are as good as estimates from other methods. Stevens *et al*. (1991) mentioned that CVM is the only technique capable of measuring existence values which Spash *et al*. (2000) opined that CVM has the ability to estimate option, existence and bequest values in addition to direct use values.

The different stages involved in CVM studies include designing and pre-testing the survey, conducting the main survey, estimating the Willingness to Pay (WTP) and/or Willingness to Accept (WTA), bid curve analysis, data aggregation and final assessment (Spash *et al*., 2000).

Contingent valuation is an example of stated preference technique. It is carried out by asking the consumers about their willingness to pay in order to obtain an environmental service. It is done by asking the respondents whether they would be willing to pay a specific amount (dichotomous or polychotomous choice) or telling them to choose from a number of options (choice modelling). Contingent valuation method can be used to value any environmental benefit by phrasing the question appropriately to the respondents. However, the limitation is that the respondents cannot make informed choices, if their understanding on the issue is limited.

Choice modelling

Attribute based methods called conjoint analysis or choice experiments (CE) or choice modelling (CM) have emerged due to their ability to analyse preference heterogeneity of consumers in environmental valuation. Choice modelling is a newer approach for obtaining stated preferences. It consists of asking respondents to choose their preferred option from a set of alternatives, where the alternatives are defined by attributes. This method minimizes some of the technical problems associated with contingent valuation, such as strategic behaviour of respondents. The disadvantage is that the responses are hypothetical and would suffer from hypothetical bias and the choices can be complex if there are many attributes.

Hedonic analysis

Hedonic pricing depends on the kind of environmental attributes which it has. For example, a house in a clean environment should command a higher price for a similar house available in a polluted environment. Thus hedonic price analysis compares the price of similar goods to attain the implicit value that buyers attach for the environmental attributes. This method requires a large sample size and therefore has limited application. Moreover, hedonic price analysis works well only when there exists a transparent market, not distorted by market failures.

Travel cost method

The travel cost method is used to understand the value from observed behaviour in a surrogate market. It generally uses information on the total expenditure incurred by the tourists or visitors to visit the place in order to obtain their demand curve for the site's services. The total benefit that the visitors obtain can be calculated from the demand curve. The travel cost method is used extensively to value the benefits of sites of recreation or tourism importance.

Benefits transfer

Benefit transfer is actually not a methodology. It refers to the use of estimates obtained in one context to estimate the values in a different context. For example, an estimate obtained by tourists viewing avifauna in one sanctuary might be used to estimate the benefit obtained from viewing birds in a different sanctuary, by using adjusted data in conjunction with some data collected from the site of interest. Benefit transfer method has been the subject of controversy as it has been often used inappropriately. As the condition of the two sites are unlikely to be identical, it is likely to have some errors.

The above techniques are widely used in economic valuation. When applied carefully, following the best practice, valuation tools provide reliable information on the changes in value of non-marketed ecosystem services that would result from anthropogenic activities or from certain management interventions. Most of the valuation tools require enormous data and if data requirements are satisfied, more reliable values can be expected. Nevertheless, the choice of valuation technique will depend on the characteristics of the case, including its scope and data availability.

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CHAPTER 19

Economic Valuation of Biodiversity-recent Approaches

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Introduction

Bio-diversity refers to the variability among living organisms from all sources including, inter alia terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within the species, between species and of the ecosystem. (UNEP, 1992). This bio-diversity is considered as world's fundamental stock due to their inherent potential.

Why economic valuation?

The link between economics and is vital to understand their value. But most of the natural resources that we use have value but not priced and also not traded in the market –E-g Air. The natural resources (NRS) need valuation because of missing market, alternatives and alternative uses of NRS, uncertainty in demand and supply of NRS, Policies for conservation of NRS and NRS accounting (Kadekodi, 2001)

Ecosystem values

Ecosystems have three distinct characteristics in valuation namely (i) existence value; (ii) intrinsic value and (iii) option value

Values of bio-diversity

Productive use value

Consumptive use value

Intrinsic value (Mc Neely, 1996)

Productive use value It is the value assigned to the products that can be harvested for exchange in formal market and is the only value of biological resources that appears in the national income accountExample: Fuel wood, fodder, timber, fish, medicinal plants

Consumptive use value: The value assigned to natural products that are consumed directly i.e., the goods that do not enter normal channels of trade. Example: A variety of Non Timber Forest Products (NTFP)

Intrinsic value: It is the value related primarily with the functions of the ecosystem but sometimes outweigh the consumptive/non-use values like, Maintenance of ecological balance, Prevention of soil erosion etc.

The different types of values that are associated with the economic valuation of the bio-diversity (or ecosystem) are detailed below.

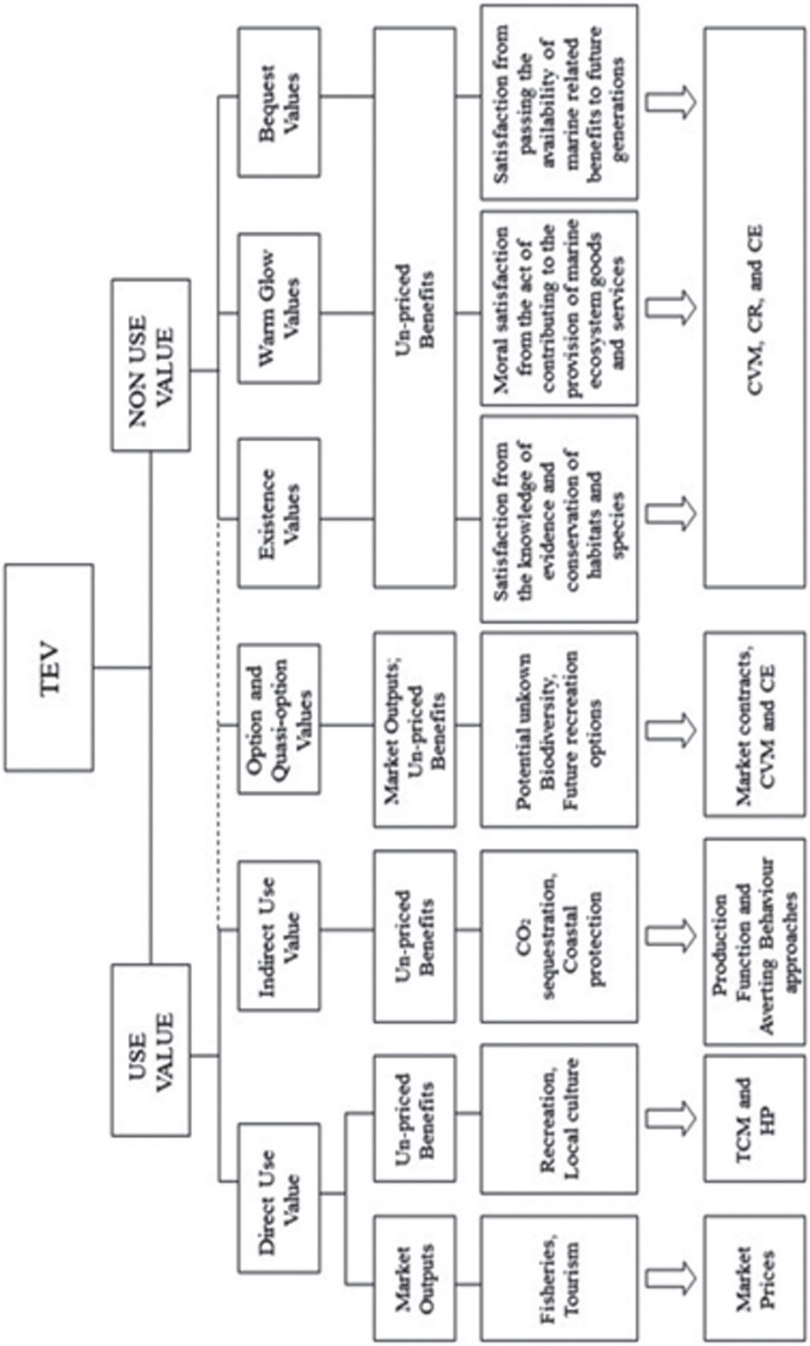

Figure 1 Total economic value (TEV)

Primary source: Cohen, Dave. "What is the Economic Value of Healthy Oceans?" Decline of the Empire. (2012)

Secondary source: Dr.Ramachandra Bhatta, 2015

The economic valuation of bio-diversity, which is also a part of the ecosystem, is estimated through **Millennium Ecosystem Assessment (MEA)** approach developed by United Nations Environment Programme **(UNEP) in 2006** as detailed below. (Figure 2 & 3)

Figure 2 Millennium Ecosystem Assessment (MEA) approach

Primary source: metrovancouver.org; Secondary source: Dr.Ramachandra Bhatta, 2015

The services provided by the ecosystem can further be grouped under four major heads namely (i) Provisioning; (ii) regulating; (iii) cultural and (iv) supporting services. The sub-components of each of these four services are also indicated based on which the economic valuation is arrived at. (Figure 3)

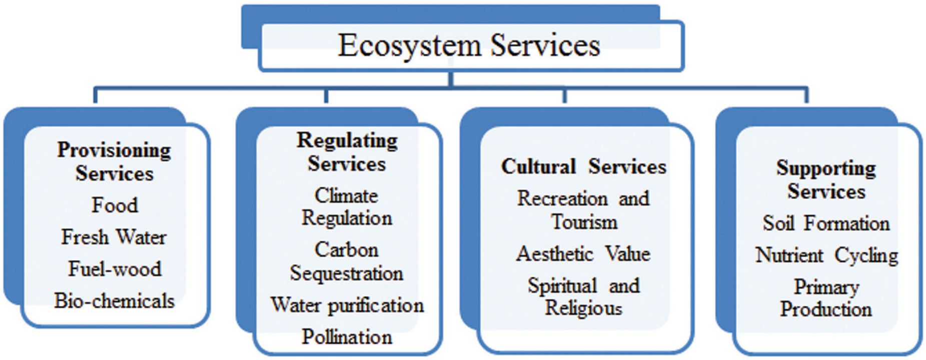

Figure 3 Classification of ecosystem services

Valuation of biodiversity

Before economic valuation of the biodiversity, the list of services provided by the various components of the biodiversity has to be enlisted as given below. (Table 1). Once the components of the biodiversity are identified such as mangroves, corals, sea weeds, sea grasses, marine mammals and others species, we can proceed to the selection of appropriate valuation methodology for these components as indicated in Table 2.

Table 1. Format for valuation of biodiversity services

Biodiversity services	Components of biodiversity					
	Mangroves	Corals	Seaweeds	Marine mammals	Sea grass	Others
	Availability (Yes or NO)	Availability (Yes or NO)	Availability (Yes or NO)	Availability (Yes or NO)	Availability (Yes or NO)	Availability (Yes or NO)
Provisioning services						
Food						
Fibre, timber, fuel						
Medicines, other resources						
Regulating services						
Biological regulation						
Freshwater storage & retention						
Hydrological balance						
Atmospheric & climate regulation						
Human disease control						
Waste processing						
Flood/storm protection						
Erosion control						
Supporting services						
Biochemical						
Nutrient cycling & fertility						
Cultural services						
Cultural & amenity						
Recreational						
Aesthetics						
Education & research						

Table 2. Tentative methodology for economic valuation of biodiversity

Biodiversity services	Components of biodiversity						Valuation method to be adopted
	Mangroves	Corals	Seaweeds	Marine mammals	Sea grass	Others	
Provisioning services*							
Food							Direct valuation based on market prices
Fibre, timber, fuel							Direct valuation based on market prices
Medicines, other resources							Direct valuation based on market prices
Regulating services							
Biological regulation Freshwater storage & retention Hydrological balance Atmospheric & climate regulation Human disease control Waste processing Flood/storm protection Erosion control							Values for these items can be taken from the studies already worked out for different ecosystems in the world in Costanza, 1997, 2000, 2014 paper on millennium ecosystem assessment.However, these values have to be reworked for our area (i.e extent say 15 sq.m or 30 sq.m) of study
Supporting services							
Biochemical							As mentioned above
Nutrient cycling & fertility							
Cultural services							
Cultural & amenity							
Recreational							Travel cost method
Aesthetics							Abstract concept. We have to use Contingent valuation method (CVM)and ask respondents, how much they will be willing to pay (WTP)for the services of biodiversity
Education & research							To use a **proxy method.** How much research work has been done on this biodiversity? How much spent on research? How many scholars have worked on this aspect? How much fees has been charged from them and related details can be collected and the approximate values can be added up

*Note: * **Provisioning service:** The major components of provisioning services include food, fresh water, fuel wood and bio-chemicals. Among them food is the most important provisioning service which addresses the nutritional security of the stakeholders. The provisioning services can be valued directly based on the market value available. The total output multiplied by the unit value per output will give you the value of the provisioning services –food.*

To get more precise estimation, we can define the services provided under each component as indicated below. We will take for example mangrove biodiversity. (Table 3)

Table 3. Tentative format for valuation of provisioning services of mangrove biodiversity

Service: Provisioning	Definition	Method and value
Food	Assessment of the marine species around the mangroves and estimation of its value	Direct pricing method
Fuel, timber etc	Revenue from cutting down trees; Sale of mangrove leaves and related aspects	Direct pricing
Medicinal value & other resources	How much of leaves or fruits or pods sold for medicine purpose	Indirect estimation (indirect pricing)

Similarly the regulating, supporting and cultural services provided by the biodiversity (Ecosystem) can be defined and appropriate methods can be used for valuation. Regarding the regulating and supporting services, the earlier studies conducted in that ecosystem can be used as a base and suitable modification (up dating) can be made for our study area (based on the geographical extent of the study area (may be in "cents", or "sq.m" or "acres" or" hectares")

The recreational and tourist values of the ecosystem or biodiversity are worked out based on the widely adopted standard methodologies as detailed below.

1. Travel cost method (TCM)

This method is used to estimate the recreational or tourism value of any ecosystem service. In case of marine biodiversity conservation, the marine parks (or) biosphere reserves (or) marine protected areas (MPA) are demarcated. Such protected areas have tourism or recreational value, which can be estimated using this method.

Travel cost method **estimates the economic value** associated with the ecosystem or sites that are used for recreation (which in turn serves as tourist spots also.), The TCM estimates the economic benefits due to (i) Changes in visiting fees (access charges); (ii) Closure of an existing recreational site; (iii) Addition of a new recreational site and (iv) Changes in environmental quality of a site. The principle behind TCM is that the **travel cost expenses of the people is a proxy to their willingness to pay (WTP) for conservation of a existing resource or facility**

In this method, initially a set of zones around the site are defined. The number of visitors from each zone is enlisted. Then, the visitation rates per 1000 population in each zone are estimated. Besides, the round trip travel distance and travel time for each zone is calculated. Then the variables influencing the per capita travels costs have to be identified using any regression models. Based on this information, the demand function is estimated. Finally the economic benefit (or) value of the site is computed as the consumer surplus i.e. the area under the demand curve)

The specimen Schedule (Work sheet to collect Secondary information) to work out the tourism value using the travel cost method in the study on **An assessment of eco-labeling as a tool for**

conservation and sustainable use of biodiversity in Ashtamudhi Lake, Kerala (South west coast of India) is given in **Annexure-I.**

2. Expressed Preference : Contingent valuation method (CVM)

This approach can be used to estimate the non-use value of marine biodiversity. This involves assigning monetary value to the non-use values of environment. In this method, the stakeholders (or) users are asked directly to express their willingness to pay (WTP) for any environmental service or benefit such as A park, walk way, marine protected area, biosphere reserve and related services. The other side of this concept namely, willingness to accept (WTA) is asked to get the opinion of the people the compensation that they can accept for giving up certain environmental benefits like pollution, construction of bridges or special economic zones and related aspects.

The CVM method comprises five steps namely, (i) definition of the problem,; (ii) deciding on mode of survey; (iii) finalizing survey design; (iv) implementation of survey and (v) compilation, analysis and report writing. Each step has a few sub components as detailed below.(Table 4)

Table 4. Steps in CVM

Sl.No	Steps	Components	
1	**Define the valuation problem**	**a)**	What services are valued?
		b)	Who are the relevant population
2	Decide the mode of survey	a)	Either personal interview or mailed one
		b)	Sample size
		c)	Time, man-power and money involved
		d)	Importance of the issue
3	Finalize the actual survey design	a)	Refer similar studies to draw the range of values
		b)	Focussed Group Discussion
		c)	Note the people knowledge on the subject under consideration
4	Actual survey implementation	a)	Select the sample using appropriate sampling method
		b)	Get maximum possible response from the respondents by repeated visits or contacting them at their convenient time and place
5	Compile, analyse and report results	a)	Suitable statistical techniques
		b)	Eliminating out layers
		c)	Deal with non-response bias (zero value for no-response**)**

Case Study

Economic valuation of the Devagad island ecosystem, Karnataka

Among the marine ecosystems, island eco system is a very sensitive and fragile ecosystem, which is threatened quickly by the human activities. This emphasizes the need to know the value of these ecosystems and before that the socio economic status of the intrinsic inhabitants or users of these eco systems to have comprehensive understanding of the situation. This will also help in formulating suitable management or policy measures for conservation of the ecosystem as well as bio-diversity. With this theme in focus, a study was undertaken to value the Devagad island ecosystem of Karnataka State using the "ecosystem approach" which takes environmental, social, and economic factors into consideration.

Devagad Island is in Uttara Kannada district of**,** Karnataka State. It is about 30 km or nautical miles off Karwar. (Baithkol landing centre). Devagad Island houses a light house and rich in terrestrial and marine biodiversity. An attempt was made to value the marine biodiversity in this island ecosystem as detailed below. (Table 5)

Table 5. Valuation of island eco system (Devagad Island): Provisional

Services of the ecosystem	Value in INR (Rs.million)	Value in US $ million	Methodology applied
1. Provisioning services	366.896	5.396	Direct pricing
2. Regulating services	375.534	5.523	Indirect estimation Costanza (1997, 2000)
3. Supporting services	38.762	3.876	As above
4. Cultural services	1.431	0.021	Travel cost method
Total	**747.738**	**10.996**	

It is seen from the table that the **provisional value** of the Devagad island ecosystem of Karnataka state is estimated at around Rs.747.74 million or US$ 10.996 million comprising Rs. 366 million (US$ 5.396 million) towards provisional services; Rs.375.534 million (US$5.523); Rs.3.876 million (US$0.057 million) for supporting services and Rs.1.316 million(US $0.021million). Thus the valuation of an ecosystem is carried out considering all the four services rendered by the biodiversity (or) eco system.

Conclusion

The ecosystem services are valued mainly to impress upon the stakeholders the importance of using the ecosystem in the most judicious way. The magnitude of the monetary tag will really make the stakeholders to think how important it is to conserve the ecosystem (Or) biodiversity or any other ecosystem services to sustain the nature.

However there is a caution that not all the ecosystem services can be economically evaluated. The process becomes complex once the ecosystem itself in the shape of a complicated net work due to the intrinsic relation among the components. To economically value the ecosystem services there is a need for a discussion between economists and ecologists for proper understanding of both economics and ecology. Brito (2005) puts rightly that poor understanding of the natural science by economists can lead to flawed results and the dissemination of inaccurate information (Primary source Beaumont, et.al, 2008). Valuing marine biodiversity has been referred as a complicated one by many researchers (Ray and Grassle, 1991, Ledoux and Turner, 2002, Patterson, 1999).

The economic valuation of any ecosystem service or biodiversity is not an end in itself. The subject is very dynamic and the valuation of one researcher need not be in conformity with the other as certain values like bequest, aesthetic, intrinsic values differ from the perception of the researchers. However, the output of such valuation studies should be treated as a yardstick and more precisely as reference points for developing the valuation process further.

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www.millenniumassessment.org

.<http://www.teebweb.org/our-publications/all-publications>

CHAPTER 20

Geo-informatics in Monitoring and Mapping of Marine Environment

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GIS has been extensively used in almost all the fields of study, be it natural sciences, social sciences, archaeology, surveying, marketing etc. and you name any field of study for that matter. It shows the importance of GIS in the present world. The strength of GIS is its ability to integrate data from different sources and carryout spatial analysis to arrive at meaningful conclusions which otherwise would not be possible. The following paragraphs throw some light on the basic concepts of GIS and how it could be used to analyse climate change (how the climate change has affected the SST over Barents Sea through the period 1891 to 2018 and to calculate Oceanic Niño Index (ONI).

Geographic information system (GIS) is a tool for making and using spatial information and it is mainly concerned with location of the features as well as properties/attributes of those features. It helps us gather, analyse and visualize spatial data for different purposes. A GIS quantifies the locations of features by recording their coordinates which are the numbers that describe the position of these features on Earth. The uniqueness of GIS is its ability to do spatial analysis. GIS helps us analyse the spatial relationships and interactions. Sometimes, GIS proves to be the only way to solve spatially-related problems and it is one of the most important tools that aid in decision making process. GIS basically helps to answer three questions; How much of what is where? What is the shape and extent of it? Has it changed over time?

Globally, on an average, GIS tools save billions of dollars annually in the delivery of goods and services through proper route planning. GIS regularly help in the day-to-day management of many natural and man-made resources, including sewer, water, power, and transportation networks. GIS help us identify and address environmental problems by providing crucial information on where problems occur and who are affected by them. It also helps us identify the source, location and extent of adverse environmental impacts. GIS enable us to devise practical plans for monitoring, managing, and mitigating environmental damage. Human impacts on the environment, conflicts in resource use, concerns about pollution, and precautions to protect public health have spurred a strong societal push for the adoption of GIS.

GIS is composed of hardware, software, data, humans and a set of organizational protocols. The selection and purchase of hardware and software is often the easiest and quickest step in the development of a GIS. Data collection and organization, personnel development and the establishment of protocols for GIS use are often more difficult and time consuming endeavours. A fast computer, large data storage capacities and a high quality, large display form the hardware foundation of most GIS. GIS software provides the tools to manage, analyse, and effectively display and disseminate spatial information. GIS as a technology is based on geographic information science and is supported by the disciplines like geography, surveying, engineering, space science, computer science, cartography, statistics etc.

In GIS, we handle the spatial and attribute data sets. Spatial data describes the absolute and relative location of geographic features while the attribute data describes characteristics of the spatial features. These characteristics can be quantitative and/or qualitative in nature. Attribute data is also referred to as tabular data. Vector and raster are two different ways of representing spatial data. Raster data is made up of pixels (or cells), and each pixel has an associated value. A digital photograph is a simple example of a raster dataset where each pixel value corresponds to a particular colour. In GIS, the pixel values may represent elevation above/below sea level, or chemical concentrations, or rainfall etc. The key point is that all of this data is represented as a grid of (usually square) cells. Vector data consists of points, lines, and polygons. The individual points are stored as pairs of (x, y) co-ordinates. The points may be joined in a particular order to create lines, or joined into closed rings to create polygons, but all vector data fundamentally consists of lists of co-ordinates that define vertices, together with rules to determine whether and how those vertices are joined.

As with many other systems, GIS basically works on the principle of '*GIGO'* that is *garbage in garbage out*. Hence the quality of data that you feed into GIS is very important and it determines the quality of the end products. But, when used wisely, GIS can help us live healthier, wealthier, and safer lives.

Hands on:

Monitoring of SST over Barents Sea

The northern Barents Sea to the north of Scandinavia and east of the remote archipelago of Svalbard is known as the Arctic warming hotspot. This region has warmed extremely rapidly; by 2.7 degrees Fahrenheit just since the year 2000. Using timeseries SST data, we would analyse how the SST varied during the period 1891 to 1900 and 2000 to 2018 taking the climatic mean monthly SST for the period 1981-2010 as the base value. We could also see how the mean Arctic Ocean SST has changed over the said periods.

Task 1: Monitoring the changes in SST over Barents Sea.

Software Required: QGIS 2.18.14 and Microsoft Excel

Data sets required:

Climatic (1981-2010) monthly mean SST (1_JAN.tif, 2_FEB.tif, 3_MAR.tif, 4_APR.tif, ……….. 12_DEC.tif)

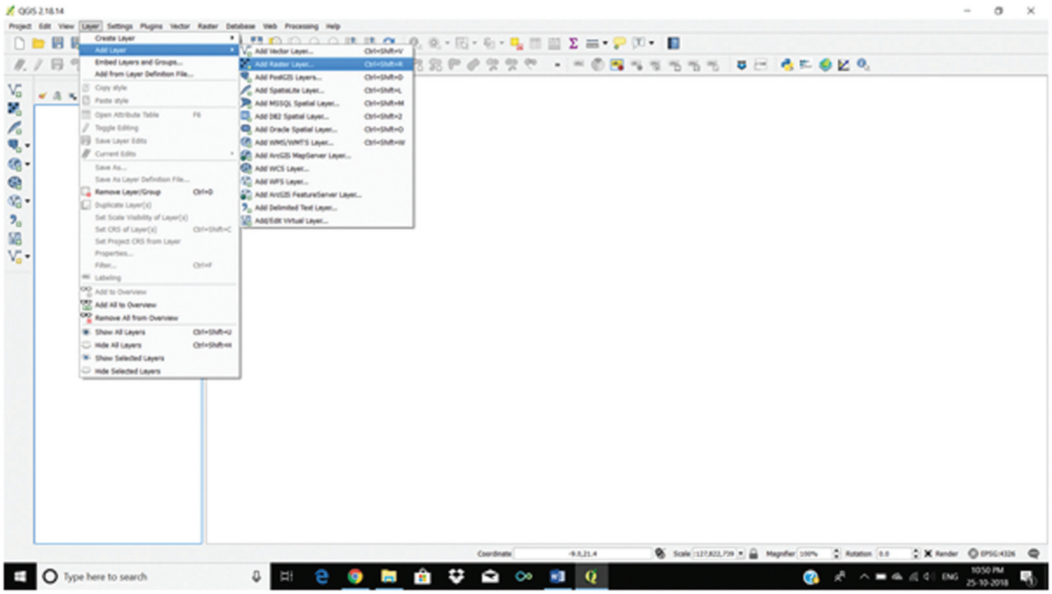
Actual monthly mean SST: Set 1 (1891_JAN.tif, 1891_FEB.tif, 1891_MAR.tif, …………. 1900_DEC.tif)

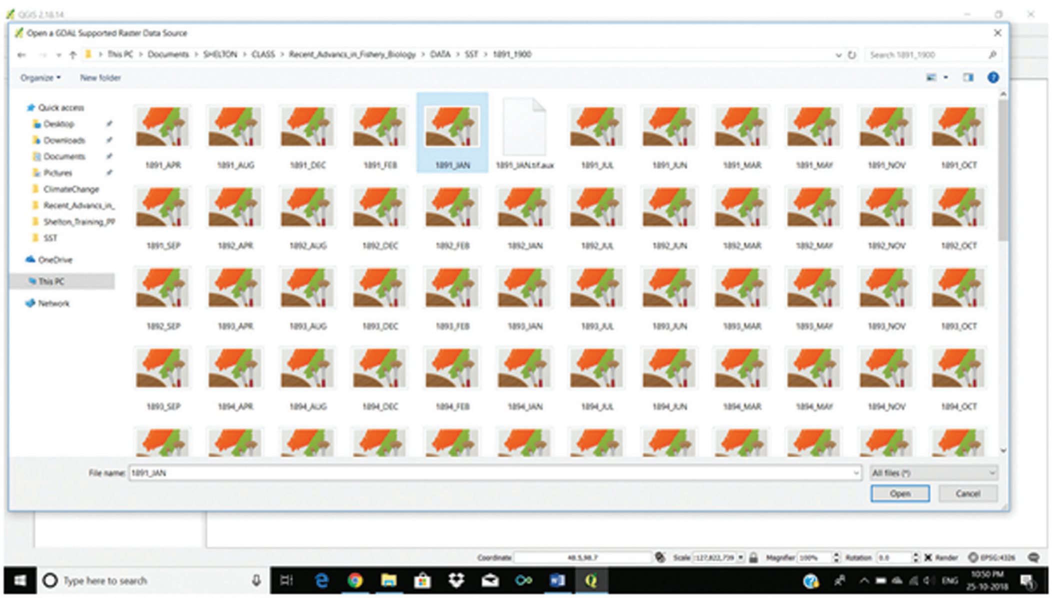
Actual monthly mean SST: Set 2 (2000_JAN.tif, 2000_FEB.tif, 2000_MAR.tif, ………… 2018_SEP.tif)

Shape file for Barents Sea: BarentsSea.shp

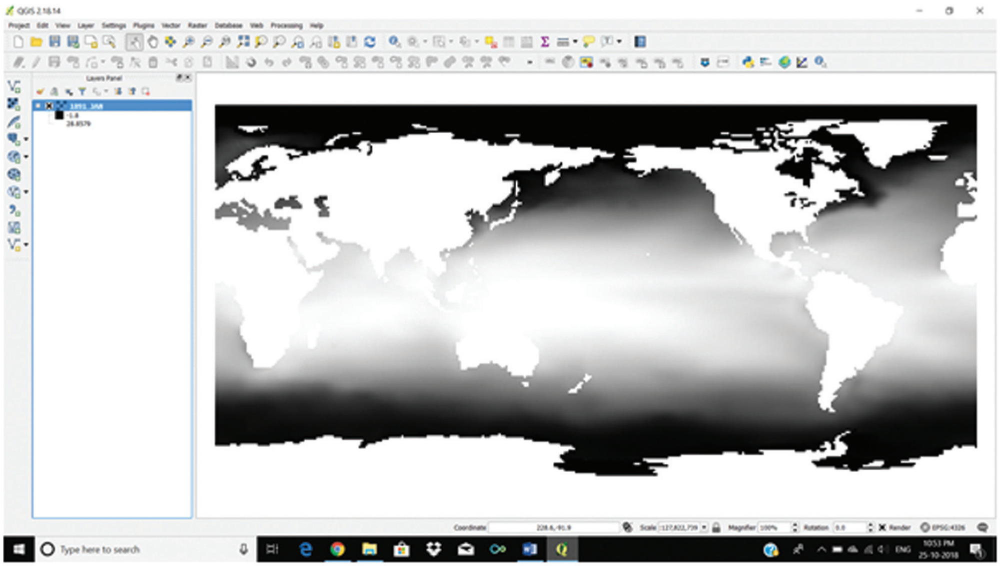
Loading SST data into QGIS:

Open QGIS -> Go to Layer menu -> Add raster layer -> Browse to the folder location -> Select the file -> 1891_JAN.tif and load the file into the map view.

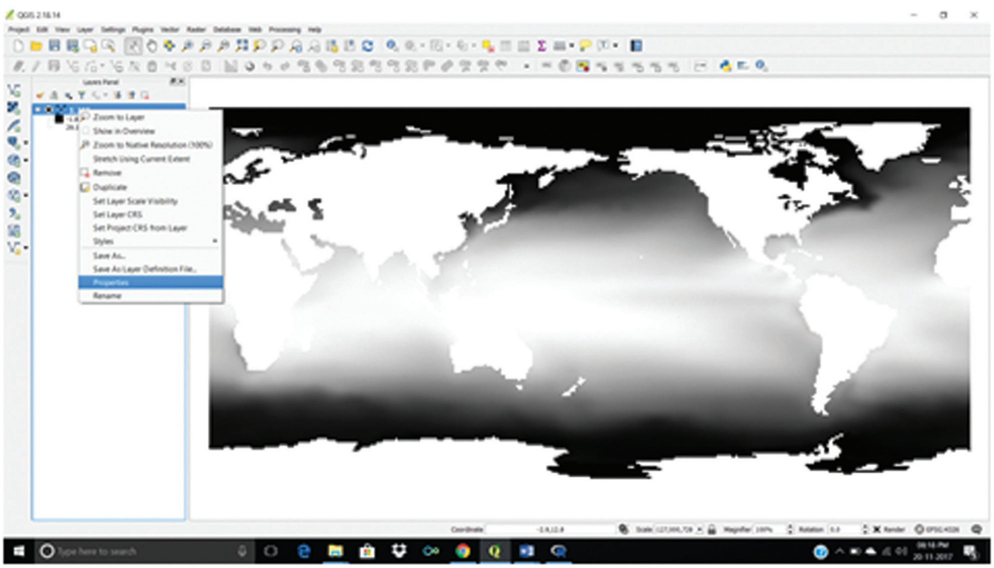




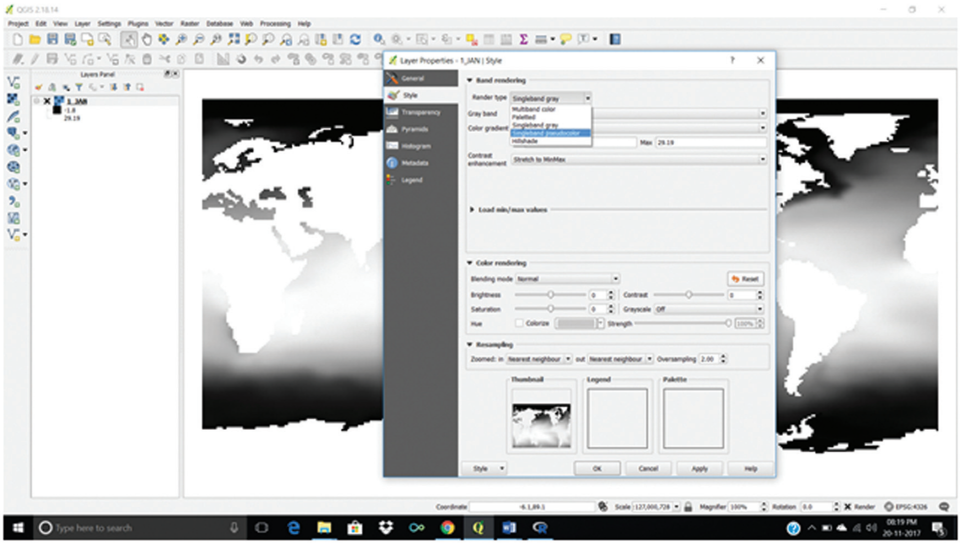
Now you get the SST data for 1891 January loaded on to the Map view as shown below



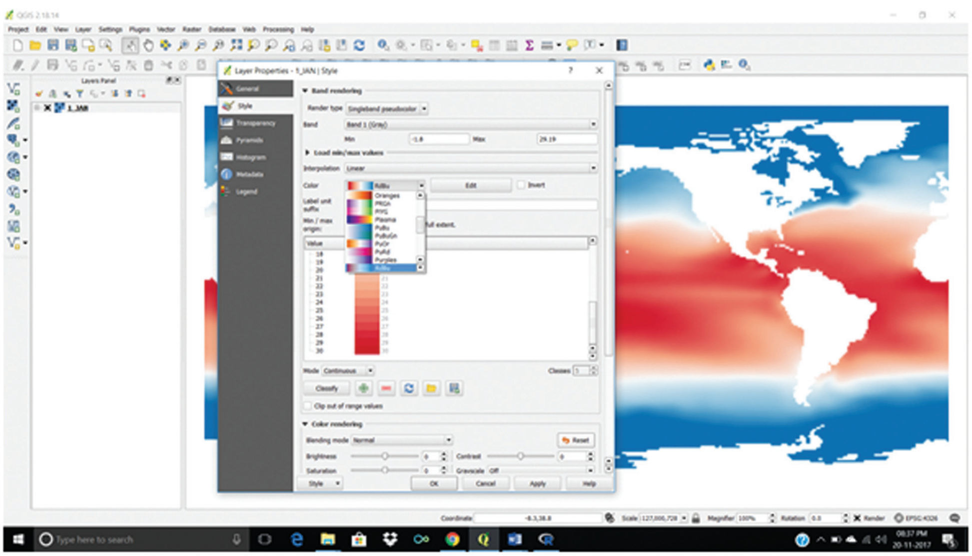
Now, to get a clear visual effect of the temperature variation, change the grey scale of the map to pseudo colour rendering. For that, right click the file name on the Layers panel (left side of the main view panel) and select the properties.



From the Layer Properties pane, go to style tab and change the band render type to 'Single band pseudo colour'.

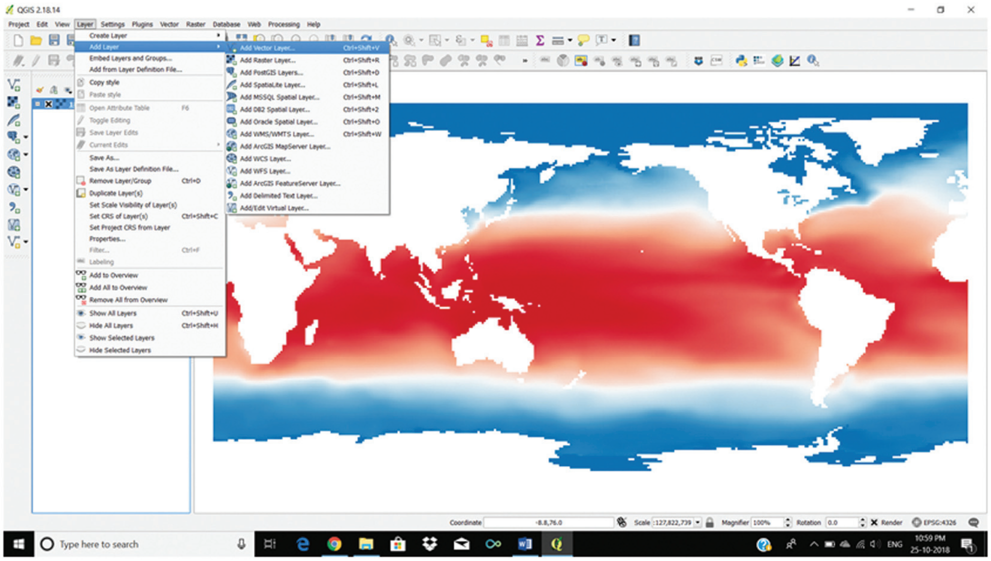


Then choose a 'Colour' band. Change the 'Mode' to 'Equal interval', set 'Classes' to '30' and press the 'Classify' button. The display will change to pseudo colour gradient as per the SST variations.

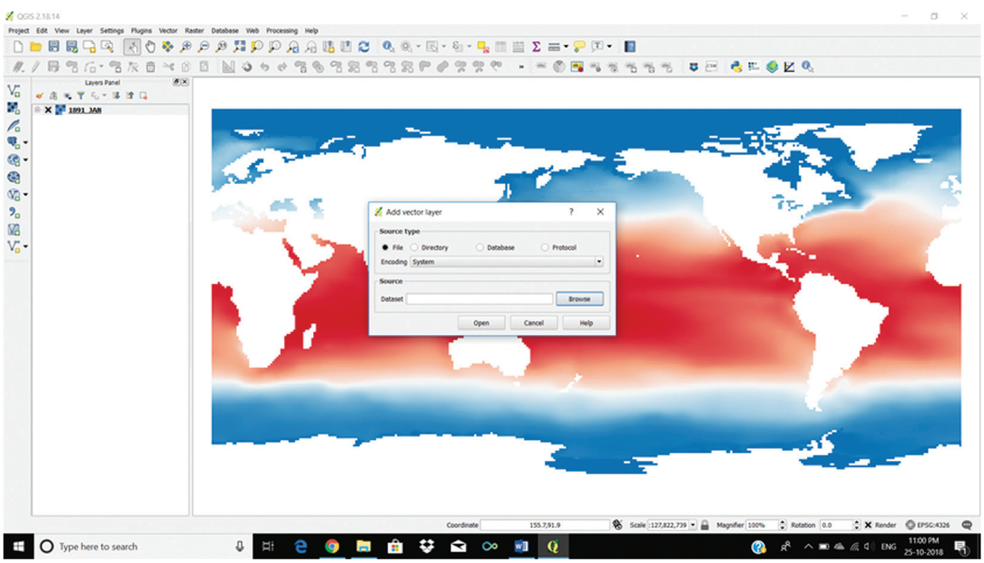


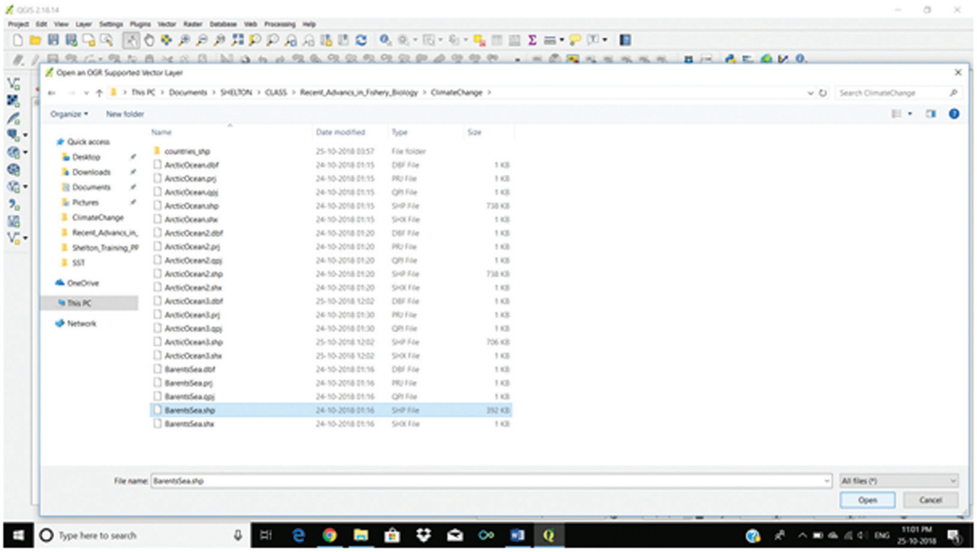
As explained above, add all the SST layers for the period 1891 to 1900 (total 120 layers).

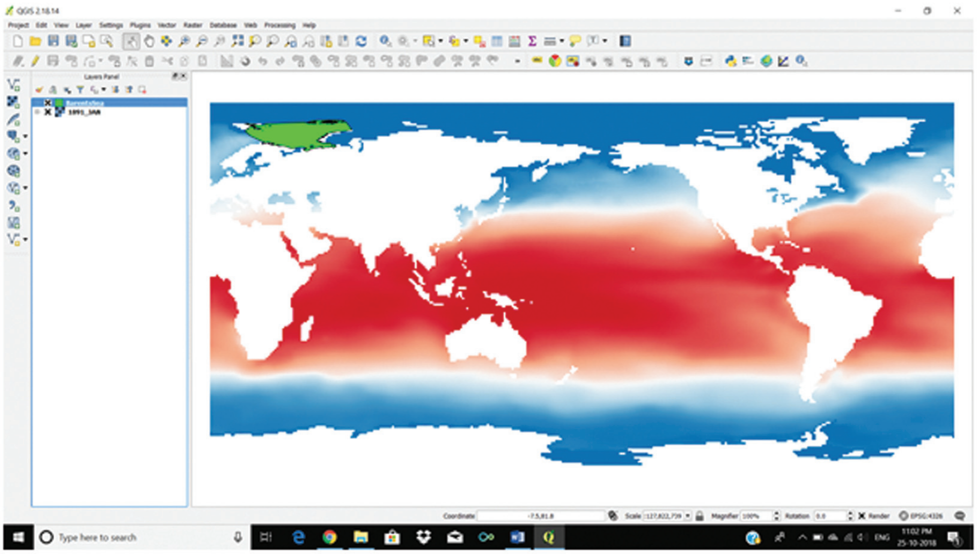
Now, load the Barents Sea shape file into QGIS. For that Go to Layers menu -> Add Layers -> Add Vector Layer.



Navigate to the required folder and open the file BarentsSea.shp

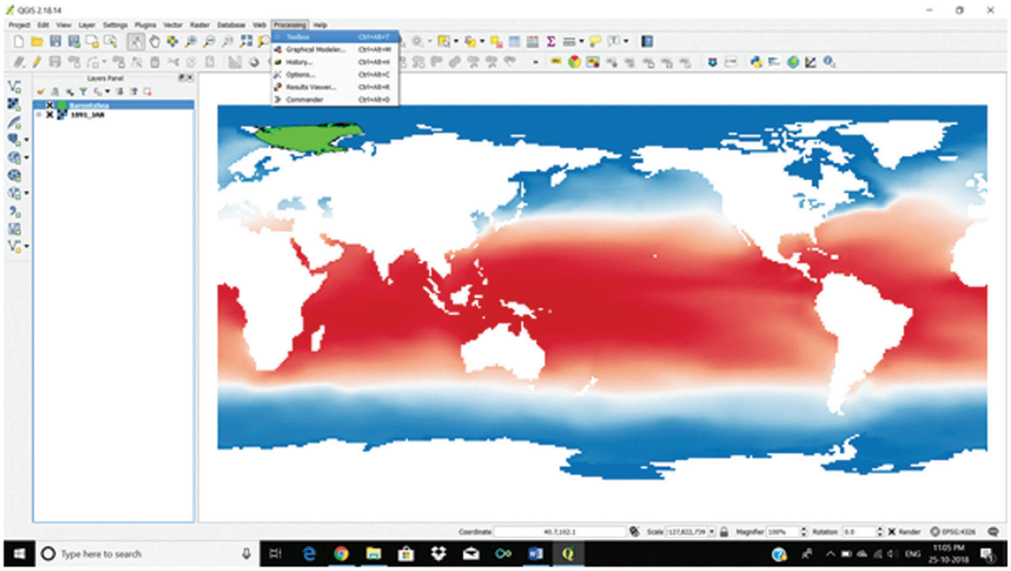


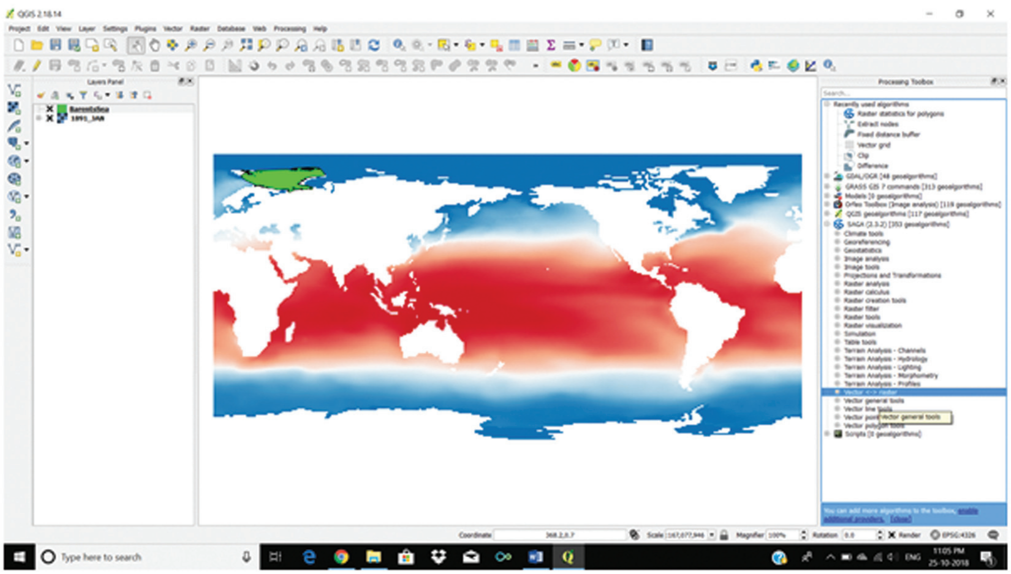


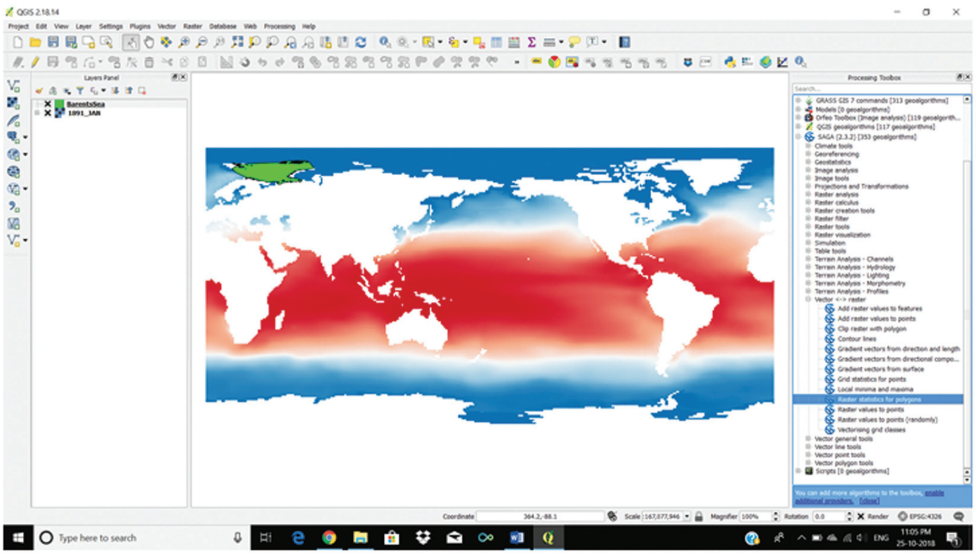


To extract the mean SST value from the 120 layers of SST, we have to use the 'SAGA' tool 'Raster Statistics for Polygons'.

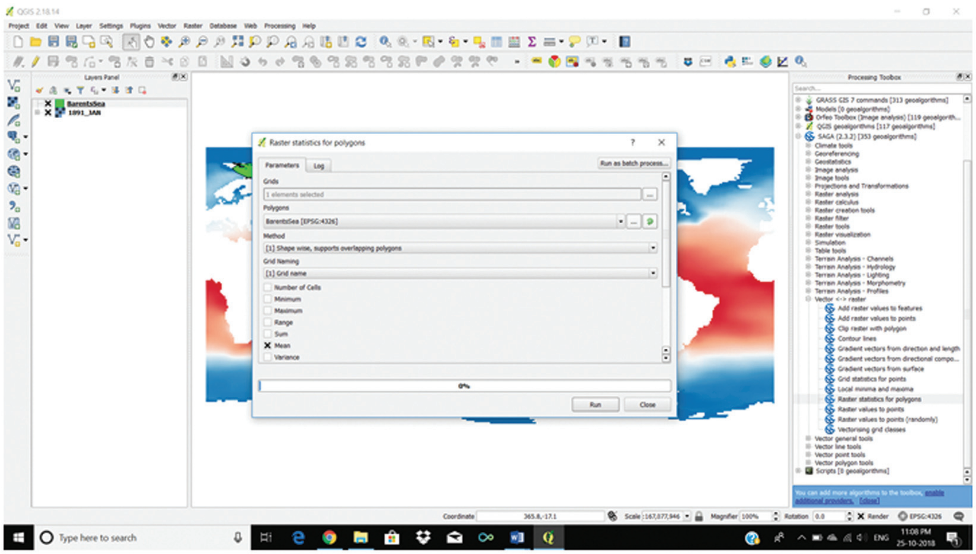
Go to 'Processing' menu -> select 'Toolbox'. On right side of the Main window, tools panel will get displayed. In the tool box, under SAGA tools, go to Vector<->Raster sub group and select the tool 'Raster Statistics for Polygons'.


QGIS 2.18.14
Project Edit View Layer Settings Plugins Vector Raster Database Web Processing Help
Type here to search

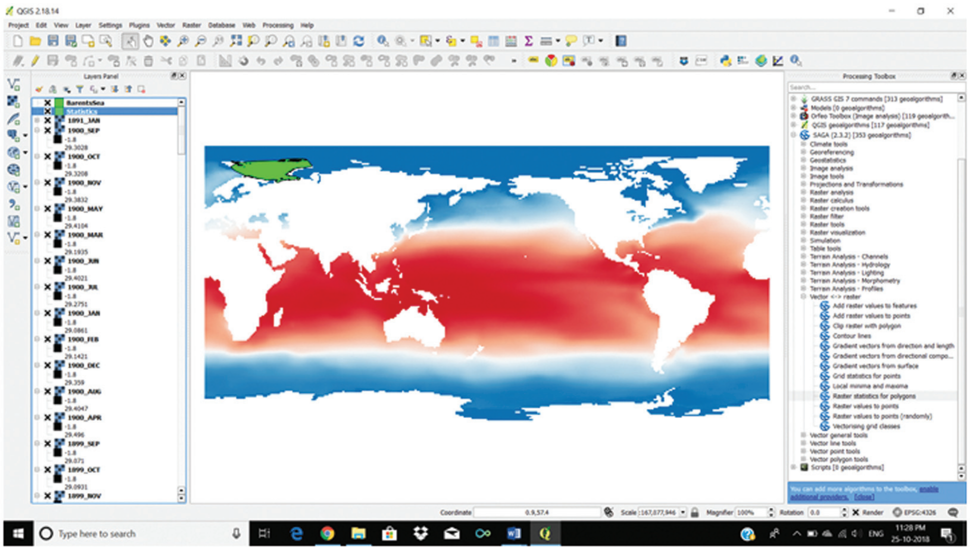

QGIS 2.18.14
Project Edit View Layer Settings Plugins Vector Raster Database Web Processing Help
Processing Toolbox
Type here to search



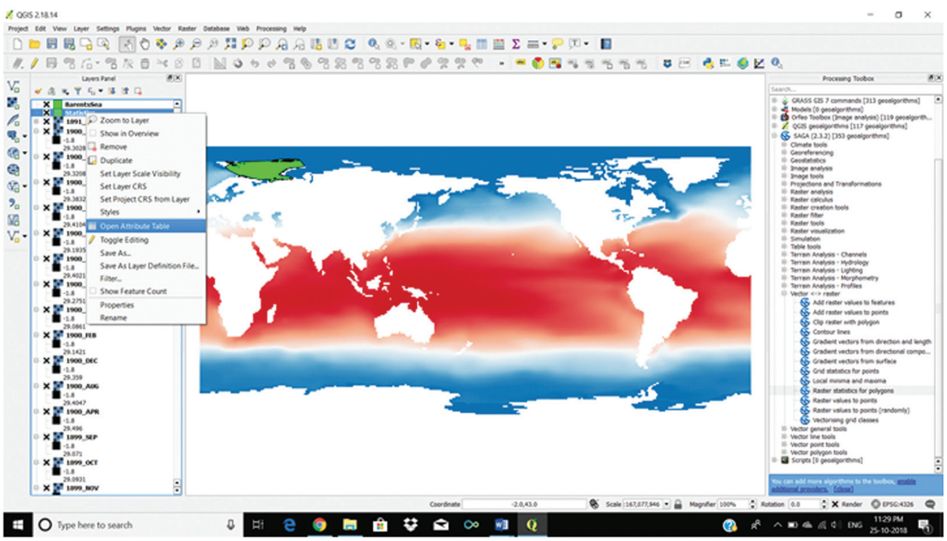
In the ‘Raster Statistics for Polygons’ tool panel, in the Grids option, select the SST datasets. For ‘Polygons’ select BarentsSea.shp’, Method-> Standard, Grid Naming -> Grid Name, tick mark ‘Mean’ and press ‘Run’.



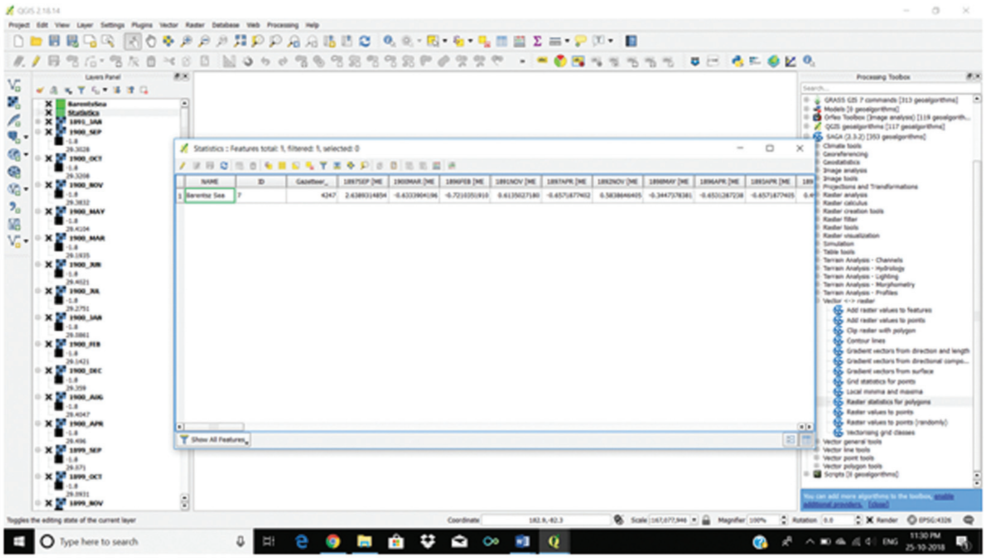
Now, you will get a ‘Statistics’ vector layer in the ‘Layers Panel’.

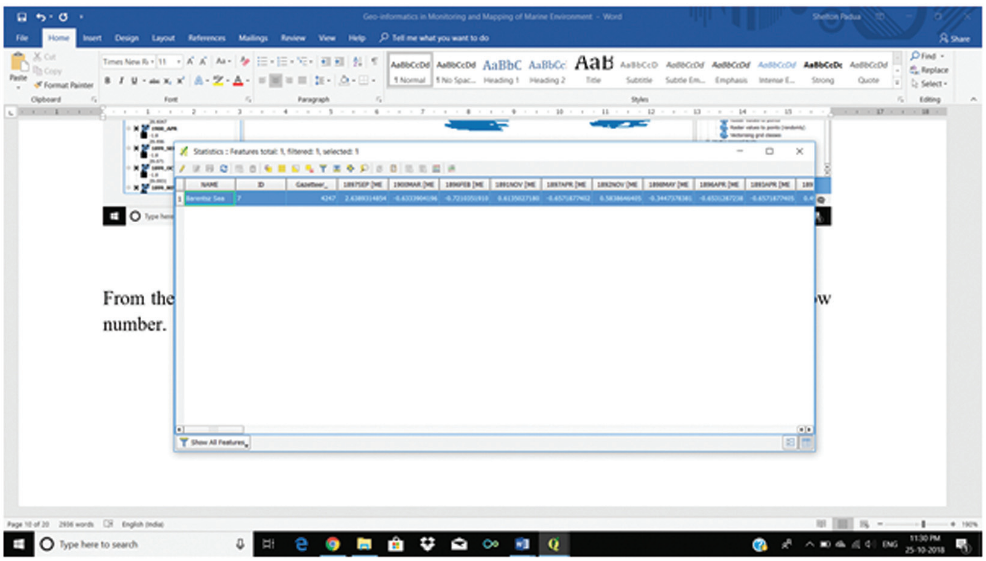


Right click on the layers panel and open the 'Open Attribute Table' by double clicking the Open Attribute Table icon. This will open up the attribute table.

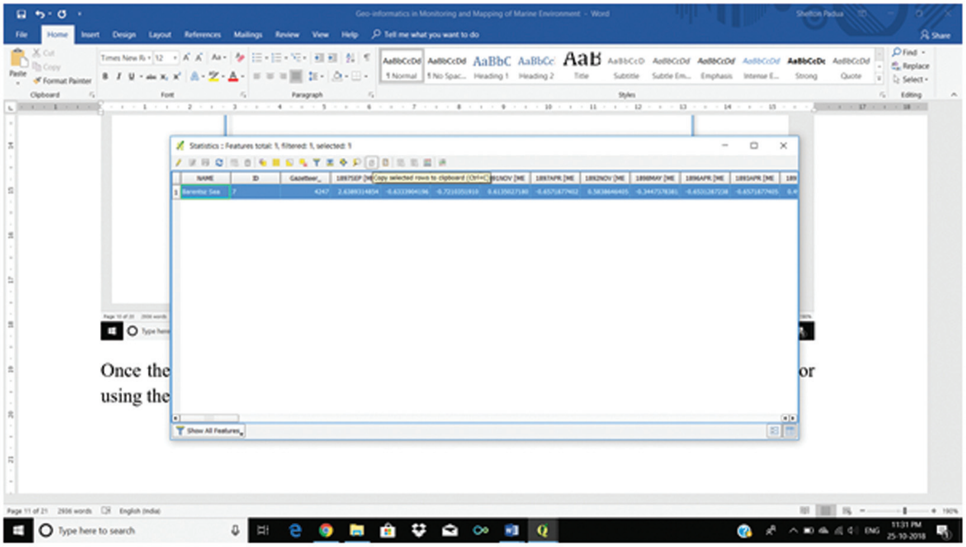


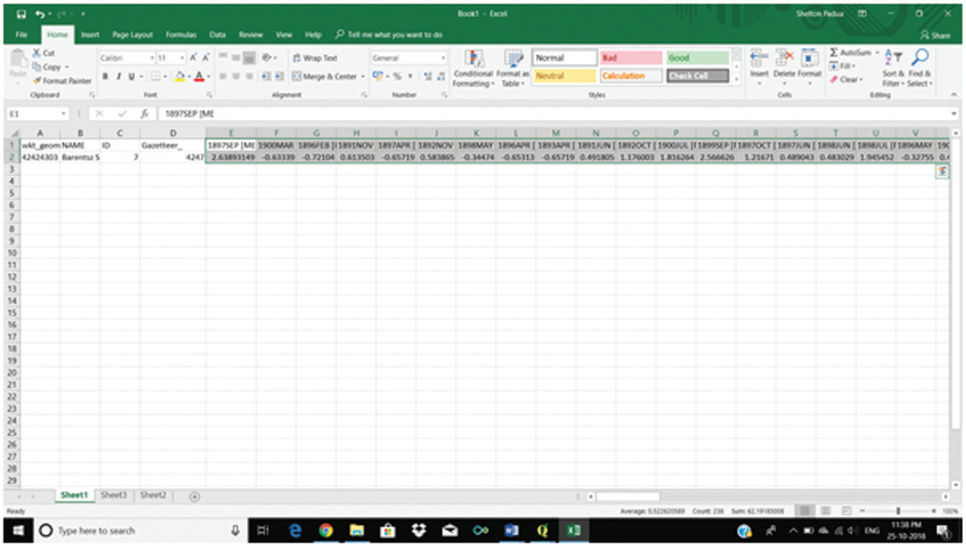
From the attribute table, select the row of attributes by 'left clicking' the corresponding row number.





Once the row is highlighted, copy the records to clipboard by clicking the ‘Copy’ button or using the keys ‘ctrl+c’. Now open a Microsoft Excel sheet and paste the copied values.





Repeat the same procedure for both climatic (1981-2010) monthly mean SST data (1_JAN to 12_DEC) and actual monthly mean SST data (2000_JAN to 2018_SEP).

Do the line plot in Excel and for SST in Barents Sea region for the periods 1891-1900, 2000 to 2018 and compare with climatic monthly mean SST and report the results.

Task 2: Monitoring the changes in SST over Arctic Ocean.

Software Required: QGIS 2.18.14 and Microsoft Excel

Data sets required:

Climatic (1981-2010) monthly mean SST (1_JAN.tif, 2_FEB.tif, 3_MAR.tif, 4_APR.tif, ………. 12_DEC.tif)

Actual monthly mean SST: Set 1 (1891_JAN.tif, 1891_FEB.tif, 1891_MAR.tif, …………. 1900_DEC.tif)

Actual monthly mean SST: Set 2 (2000_JAN.tif, 2000_FEB.tif, 2000_MAR.tif, ………… 2018_SEP.tif)

Shape file for Arctic Ocean: ArcticOcean.shp

As explained in task 1, load different SST layers in to QGIS and extract the mean value of SST over Arctic Ocean using the shape file provided, for the study period.

Load these extracted values in to Excel and compare with the climatic mean monthly SST of the Arctic Ocean region and report the results.

Mapping the Progress of El Nino/La Nina using ONI

El Niño and La Niña are the two phases of the El Niño-Southern Oscillation (ENSO) cycle. The ENSO cycle describes the fluctuations in temperature between the ocean and atmosphere in the east-central Equatorial Pacific. La Niña is referred to as the cold phase of ENSO and El Niño as the warm phase of ENSO. These deviations from normal sea surface temperatures can have large-scale impacts not only on ocean processes, but also on global weather and climate. El Niño and La Niña episodes typically last nine to 12 months, but some prolonged events may last for years. The frequency of El Niño and La Niña episodes can be quite irregular, but El Niño and La Niña events occur on average every two to seven years. Typically, El Niño occurs more frequently than La Niña.

El Niño

El Niño means The Little Boy, or Christ Child in Spanish. El Niño was originally recognized by fishermen off the coast of South America in the 1600s, with the appearance of unusually warm water in the Pacific Ocean around December. The term El Niño refers to the large-scale ocean-atmosphere climate interaction linked to a periodic warming in sea surface temperatures across the central and east-central Equatorial Pacific. Typical El Niño effects are likely to develop over North America during the upcoming winter season. Those include warmer-than-average temperatures over western and central Canada, and over the western and northern United States. Wetter-than-average conditions are likely over portions of the U.S. Gulf Coast and Florida, while drier-than-average conditions can be expected in the Ohio Valley and the Pacific Northwest. The presence of El Niño can significantly influence weather patterns, ocean conditions, and marine fisheries across large portions of the globe for an extended period of time.

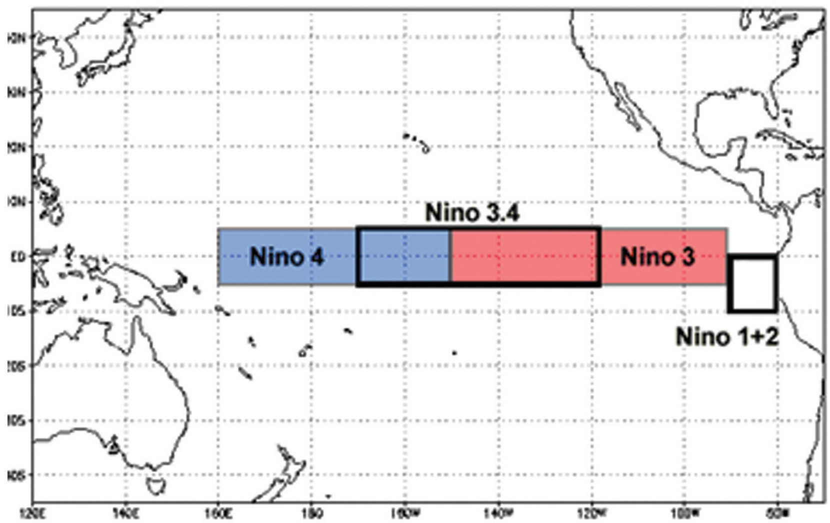
La Niña

La Niña means The Little Girl in Spanish. La Niña is also sometimes called El Viejo, anti-El Niño, or simply “a cold event.” La Niña episodes represent periods of below-average sea surface temperatures across the east-central Equatorial Pacific. Global climate La Niña impacts tend to be opposite those of El Niño impacts. In the tropics, ocean temperature variations in La Niña also tend to be opposite those of El Niño.

ENSO events are thought to have been occurring for thousands of years. Modern day research and reanalysis techniques have find that at least 26 El Niño events since 1900 with the 1982-83, 1997–98 and 2015–16 events among the strongest on record.

Different countries have different criteria to determine what constitutes an El Niño / La Niña event, which is tailored to their specific interests. For example, the Australian Bureau of Meteorology looks at the trade winds, Southern Oscillation Index (SOI), weather models and sea surface temperatures in the Nino 3 and 3.4 regions, before declaring an El Niño. However, the Japan Meteorological Agency declares that an El Niño event has started when the average five-month sea surface temperature deviation for the NINO 3 region, is over 0.5 °C (0.90 °F) warmer for 6 consecutive months or longer. The Peruvian government declares that an El Nino is under way, if the sea surface temperatures in the Nino 1 and 2 regions, equal or exceed +0.4 °C for at least 3 months.

The Oceanic Niño Index (ONI) is the standard used by NOAA for identifying El Niño (warm) and La Niña (cool) events in the tropical Pacific. It is the running 3-month mean SST anomaly for the Niño 3.4 region (i.e., 5^oN-5^oS, 120^o-170^oW). The events are defined as 5 consecutive overlapping 3-month periods at or above the $+0.5^oC$ anomaly for warm (El Niño) events and at or below the -0.5 ^oC anomaly for cold (La Niña) events. The threshold is further categorized as Weak (with a 0.5 to 0.9 SST anomaly), Moderate (1.0 to 1.4), Strong (1.5 to 1.9) and Very Strong (e” 2.0) events.



Spatial Extent of Nino regions

Spatial Extent of Nino regions

It has been found that necessary condition for the development and persistence of deep convection (enhanced cloudiness and precipitation) in the Tropics develops when the local SST is 28°C or greater. Once the pattern of deep convection has been altered due to anomalous SSTs, the tropical and subtropical atmospheric circulation adjusts to the new pattern of tropical heating, resulting in anomalous patterns of precipitation and temperature that extend well beyond the region of the equatorial Pacific. An SST anomaly of +0.5°C in the Niño 3.4 region is sufficient to reach this threshold from late March to mid-June. During the remainder of the year a larger SST anomaly, up to +1.5°C in November-December-January, is required in order to reach the threshold to support persistent deep convection in that region.

Task 3: Categorize the years into El Nino/La Nina or normal year based on ONI.

Software Required: QGIS 2.18.14 and Microsoft Excel

Data sets required:

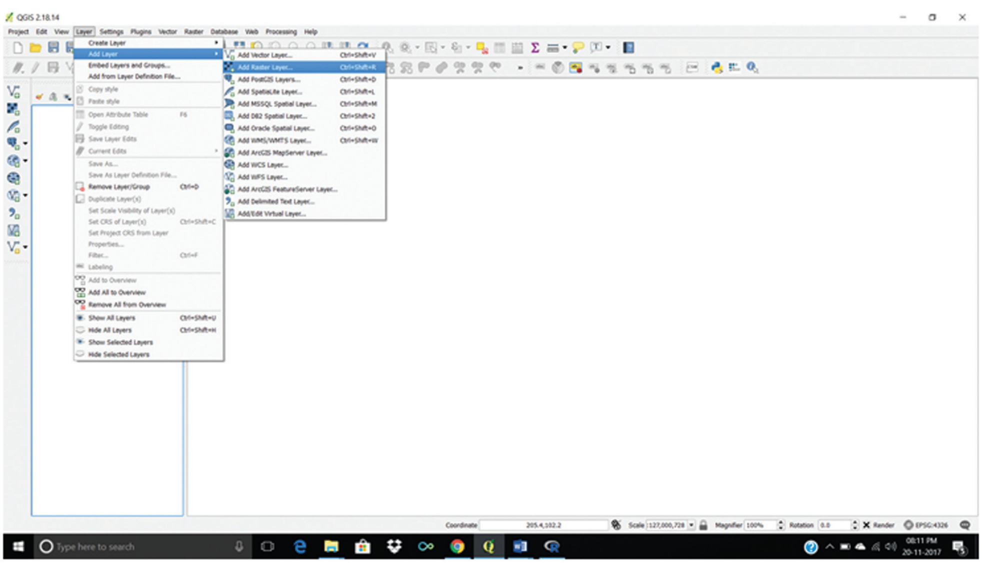
Climatic (1981-2010) monthly mean SST (1_JAN.tif, 2_FEB.tif, 3_MAR.tif, 4_APR.tif, ……….. 12_DEC.tif)

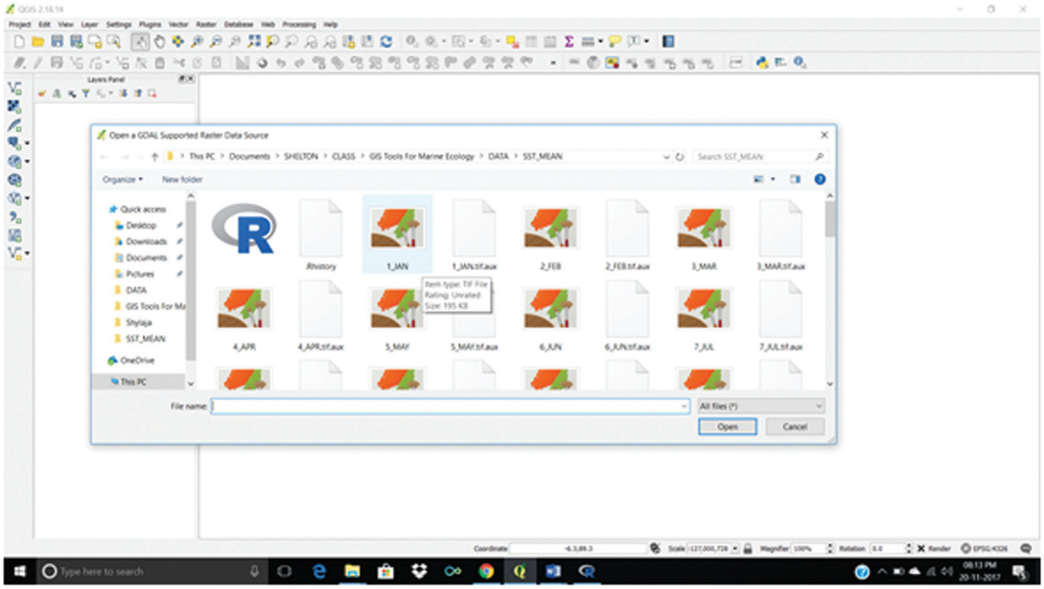
Actual monthly mean SST (2015_JUN.tif, 2015_JUL.tif, 2015_AUG.tif, ………… 2017_OCT.tif)

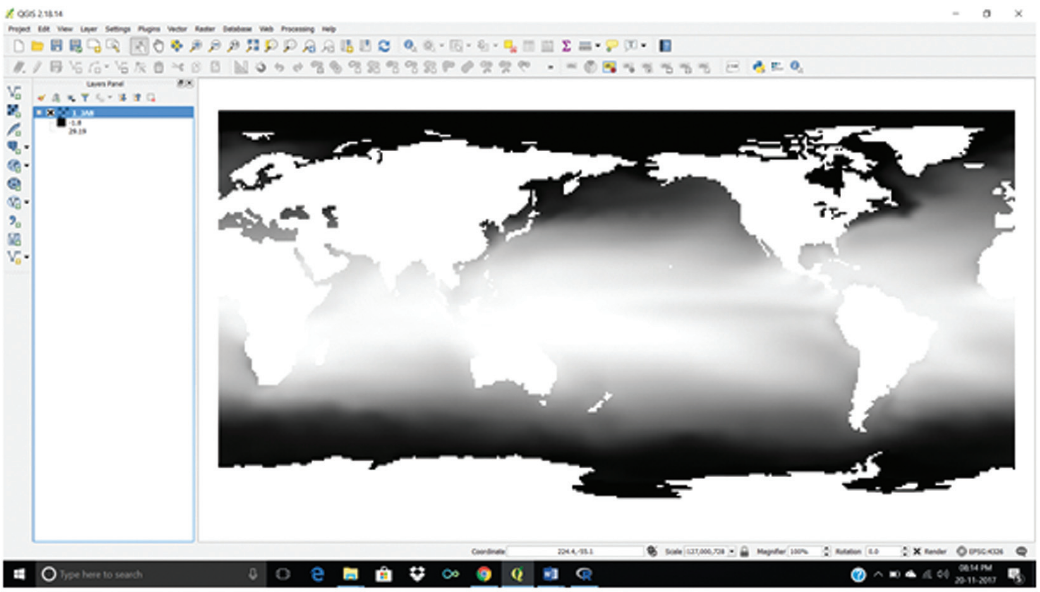
Shape file for Nino 3.4 region: NiNo_3.4_Poly.shp

Loading SST data into QGIS:

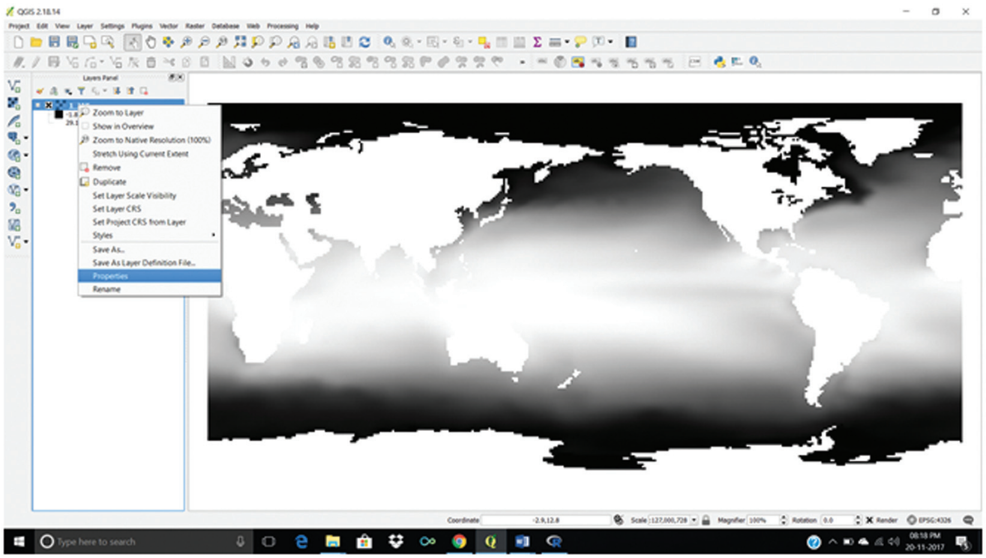
Open QGIS -> Go to Layer menu -> Add raster layer -> Browse to the folder location -> Select the file -> 1_JAN.tif and load the file into the map view.



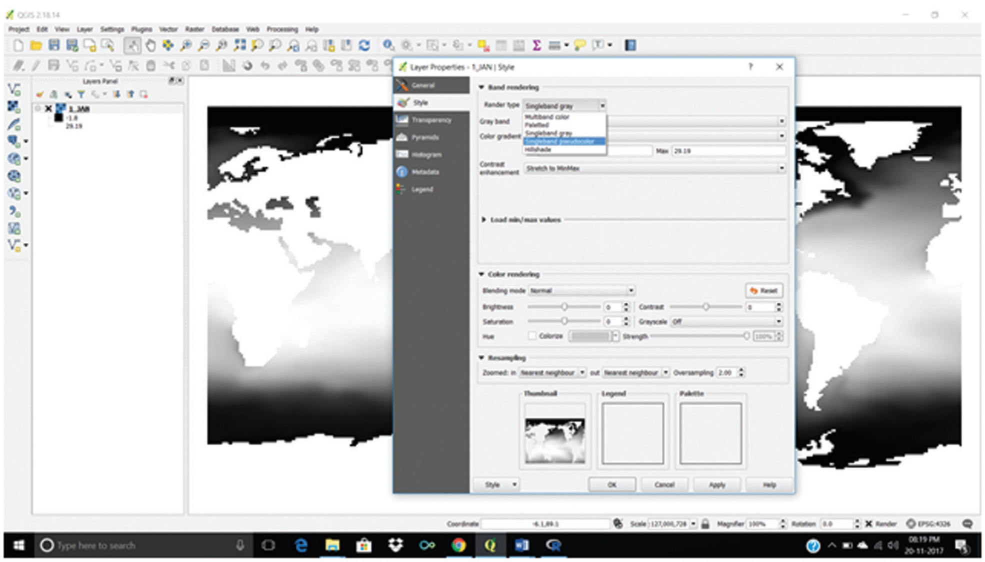




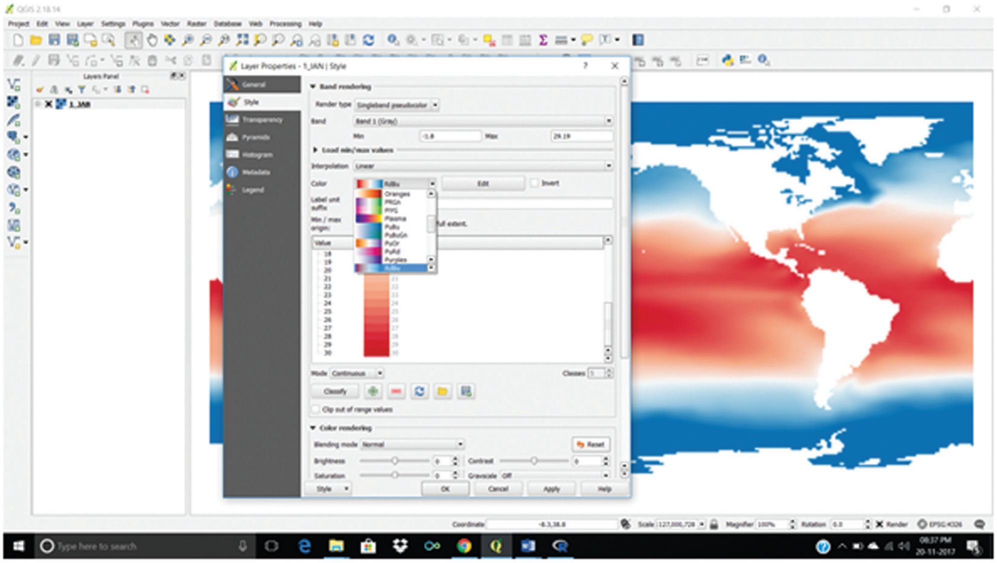
Now, to get a clear visual effect of the temperature variation, change the grey scale of the map to pseudo colour rendering. For that, right click the file name on the Layers panel (left side of the main view panel) and select the properties.



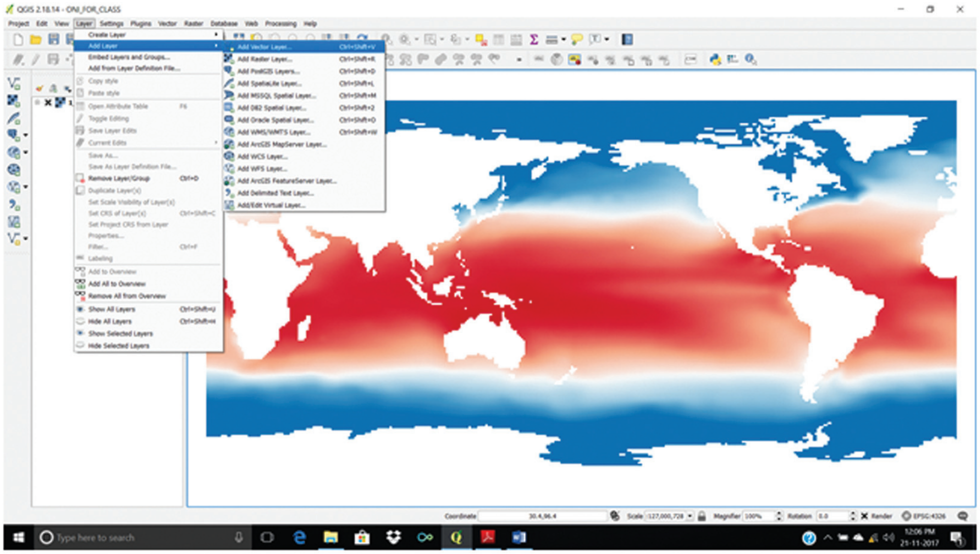
From the Layer Properties pane, go to style tab and change the band render type to 'Single band pseudo colour'.



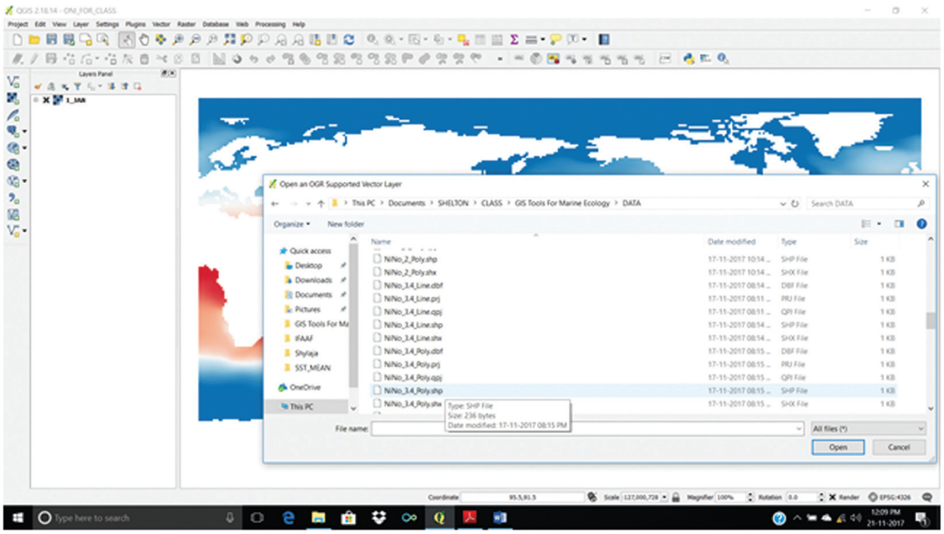
Then choose a 'Colour' band. Change the 'Mode' to 'Equal interval', set 'Classes' to '30' and press the 'Classify' button. The display will change to pseudo colour gradient as per the SST variations. Likewise, load all the SST layers.



Now, we have to load the shape file for Nino 3.4 region. Go to Layers menu -> Add Layers -> Add Vector Layer.

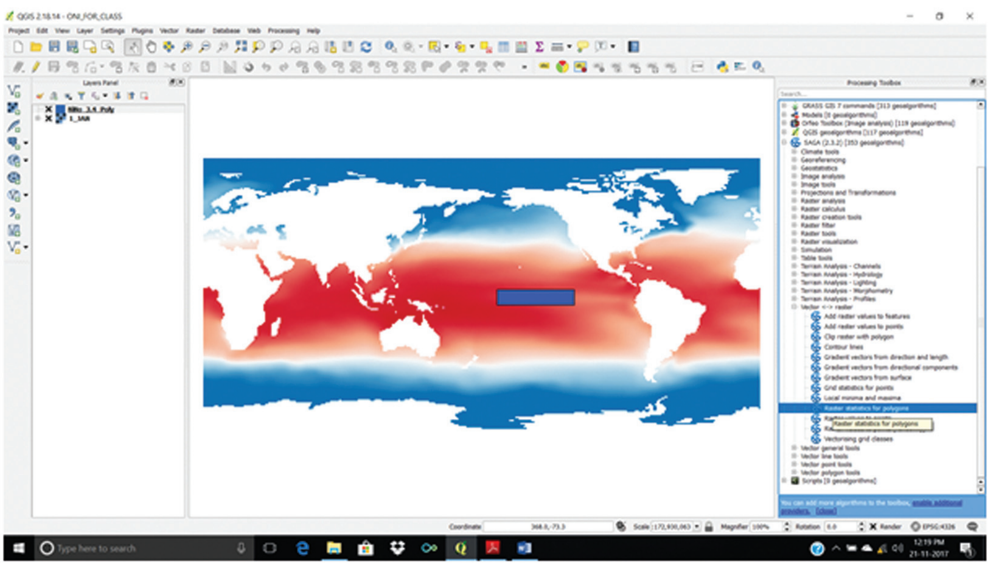


Browse to the file 'NiNo_3.4_Poly.shp' and open it.

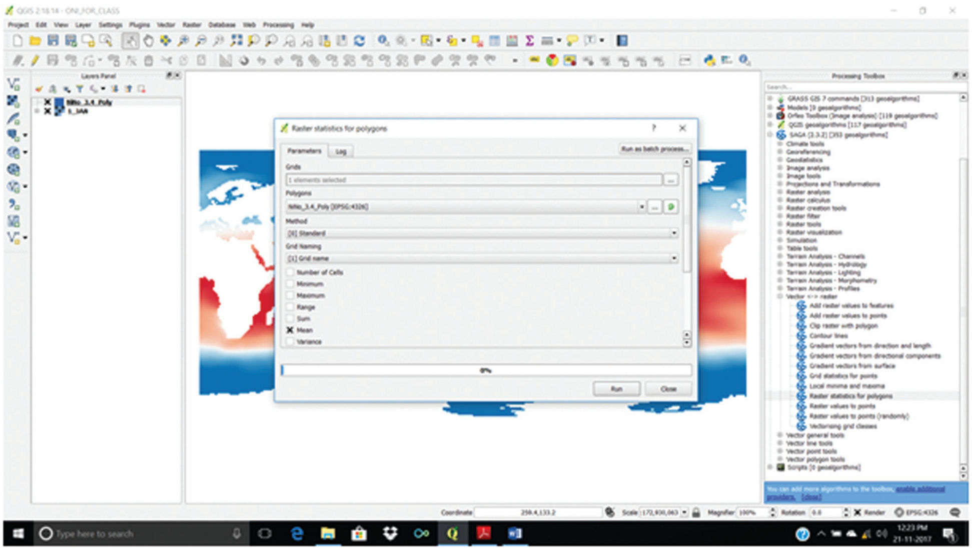


Now, we have to extract the mean value of SST from the Nino 3.4 region. For that we have to use the 'SAGA' tool 'Raster Statistics for Polygons'.

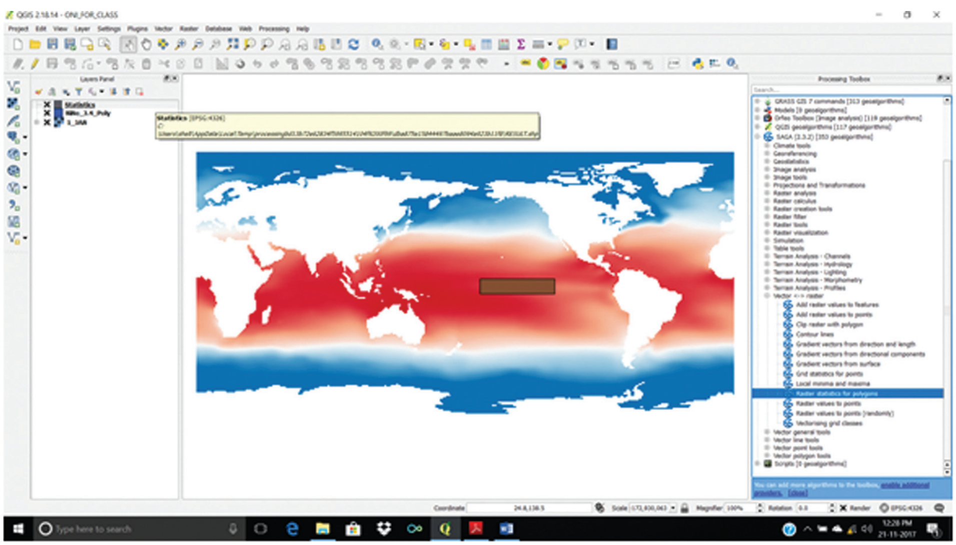
Go to 'Processing' menu -> select 'Toolbox'. On right side of the Main window, tools panel will get displayed. In the tool box, under SAGA tools, go to Vector<->Raster sub group and select the tool 'Raster Statistics for Polygons'.



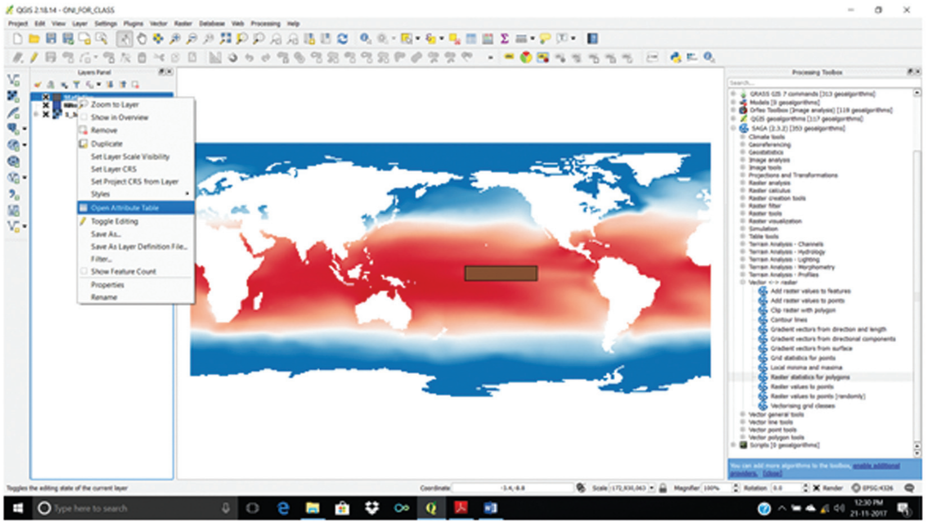
In the 'Raster Statistics for Polygons' tool panel, in the Grids option, select the SST datasets. For 'Polygons' select NiNo_3.4_Poly.shp', Method-> Standard, Grid Naming -> Grid Name, tick mark 'Mean' and press 'Run'.



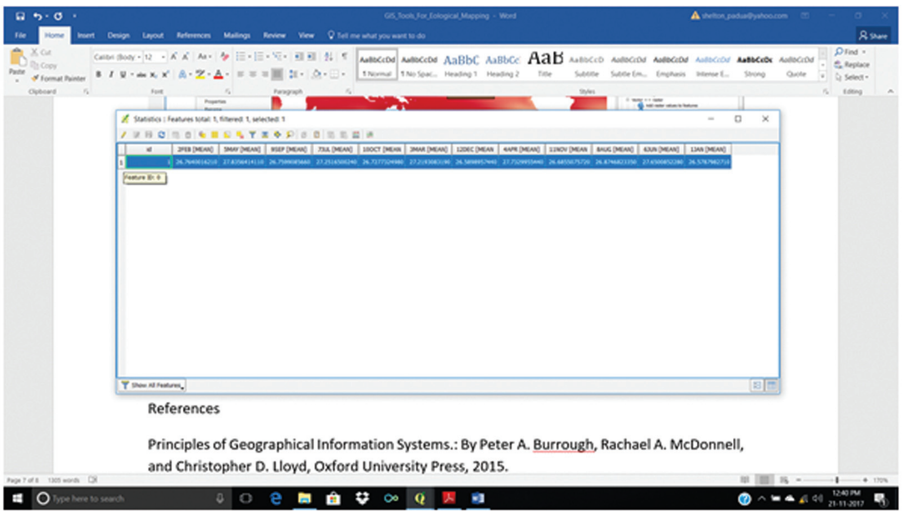
Now, you will get a ‘Statistics’ vector layer in the ‘Layers Panel’.



Right click on the layers panel and open the ‘Open Attribute Table’ button. This will open up the attribute table.

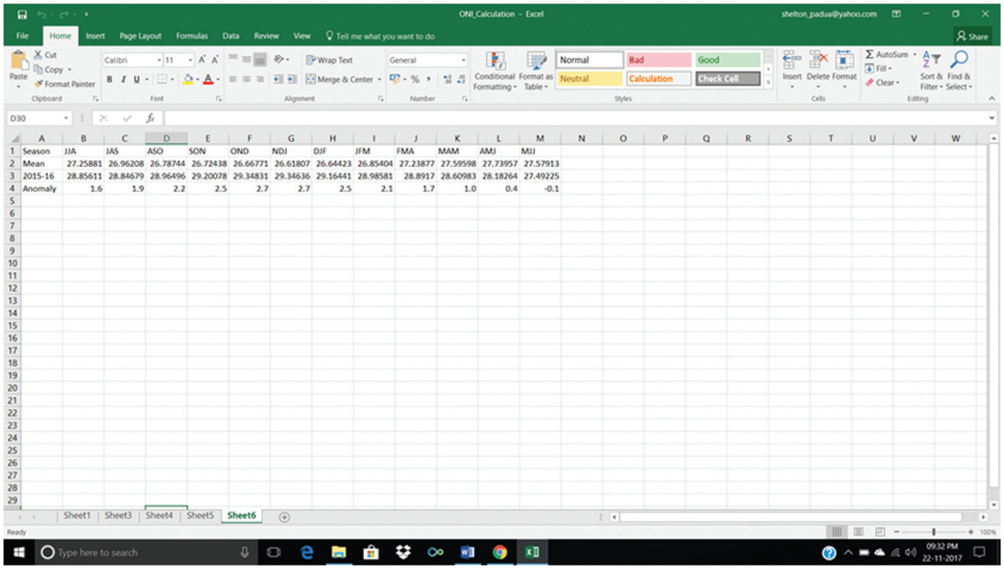


From the attribute table, select the row of attributes by 'left clicking' the corresponding row number.



Once the row is highlighted, copy the records to clipboard by clicking the 'Copy' button or using the keys 'ctrl+c'. Now open a Microsoft Excel sheet and paste the copied values. Do the procedure for both climatic monthly mean SST data (1_JAN to 12_DEC) and actual monthly mean SST data (2015_JUN to 2017_OCT).

Calculate the three months running mean from 2015_JUN to 2017_OCT and three months climatic running means. Now, find the SST anomaly (difference between these two sets of running means).



Now, see if the SST anomaly qualifies for El Nino/La Nina or normal year as per the criteria and report accordingly.

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CHAPTER

21

Marine Crab Resources of India with Facts on Life Cycle and Biology

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Introduction

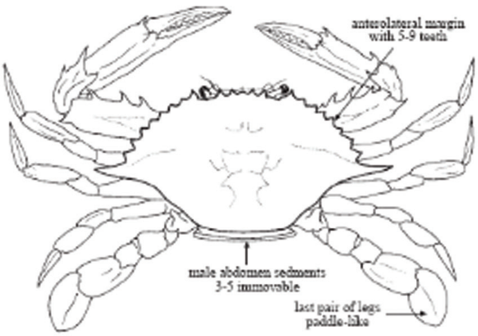
Crabs belong to the order Decapoda and they can be can be classified into two main groups, brachyuran crabs (infraorder Brachyura) and anomuran crabs (infraorder Anomura). Most species of Brachyura, or true crabs, can easily be separated from the so-called “false crabs” belonging to the infraorder Anomura by having five pairs of locomotory appendages of a crab (the pereiopods) are made up of a pair of usually powerful chelipeds (legs carrying a chela or pincer) and normally of four pairs of walking (or ambulatory) legs. The first appendage is referred to as the cheliped and the last four appendages (walking legs) as legs. The claw (or chela) itself consists of a palm (or manus) and two fingers, one of which is movable (the dactylus or movable finger), whereas the other one (Propodus/pollex) is fixed. The tips or edges of the fingers may be pectinated. In some families the last pair or all walking legs are modified for swimming or burrowing, as seen in the Portunidae (Carpenter and Niem, 1998).

Trivedi et al., (2018) published an annotated checklist of the marine brachyuran crabs occurring in Indian waters, with a total of 910 species belonging to 361 genera and 62 families. The highest number of species were recorded from the Andaman and Nicobar Islands (588 species) while the smallest number were from Goa and Karnataka state (82 species). The records indicate that the east coast of India, with 803 species, is more diverse than the west coast, which has 446 species.

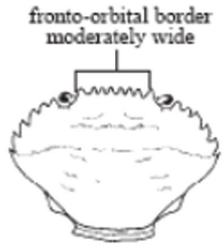
Most of the edible crabs caught from marine and brackish water environments belong to the family Portunidae. In the Indian Ocean, the crab fauna of Portunidae family is included under sub families, Podophthalmidae (Borradaile), Catoptrinae (Sakai), Portuninae (Rafinesque), Thalamitinae (Paul’son), Caphyrinae (Alcock), Carcininae (Macleay) and Polybiinae (Ortmann). In the seas around India, five genera of Portuninae have been reported by various authors. They are *Scylla, Portunus*, *Charybdis, Lupocyclus* and *Thalamita*. Among them the first three genera contribute to the commercial crab fishery Commercially important species are *Scylla* spp. (Mud crabs), *Portunus pelagicus (blue swimmer crab)*, *P. sanguinolentus (three spotted crab), Charybdis feriatus (crucifix crab), C. lucifera* (Yellowish brown crab)*, C.natator* (line crab) and *Podophthalmus vigil* (long eye-stalk crab).

Portunidae

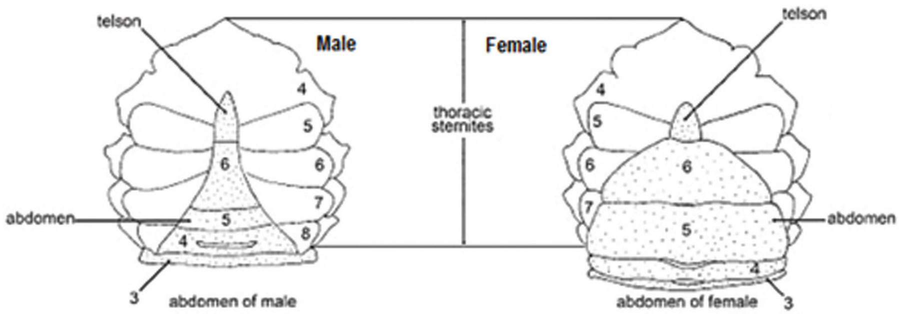
Carapace hexagonal, transversely ovate to transversely hexagonal, sometimes circular; dorsal surface relatively flat to gently convex, usually ridged or granulose; front broad, margin usually multidentate; usually 5 to 9 teeth on each anterolateral margin, posterolateral margins usually distinctly converging. Endopodite of second maxillipeds with strongly developed lobe on inner margin. Legs laterally flattened to varying degrees, last 2 segments of last pair paddle-like. Male abdominal segments 3 to 5 completely fused, immovable.



a) *Thalamita*



b) *Charybdis*



thoracic sternum and abdomen (ventral view)

Mature Male **Berried female**

Shape of abdomen in male and female (different stages) crabs

Immature female **Mature female**

Key to species of interest to fisheries occurring in the area

1a. Carapace with 2 anterolateral teeth; eyes very long, reaching lateral edge of carapace (Fig. 1) . . . . ***Podophthalmus vigil***

1b. Carapace with more than 2 anterolateral teeth; eyes normal in size **2**

2a. Carapace rounded; ventral surface of palm with stridulatory (sound-producing) ridges (Fig. 2a) . . . . ***Ovalipes punctatus***

2b. Carapace transversely ovate; palm without any stridulatory (sound-producing) ridges (Fig. 2b) ***3***

Fig. 1 *Podophthalmus vigil*

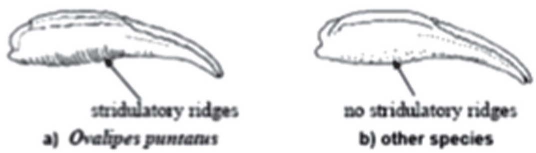


Fig. 2 chela in ventral view

3a. Five to 7 teeth on each anterolateral margin (Fig. 3a-c) **4**

3b. Nine teeth on each anterolateral margin (Fig. 3d) **12**

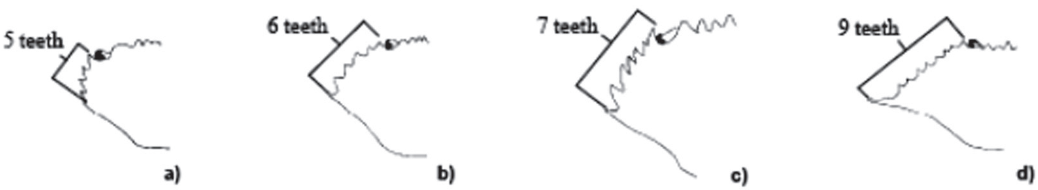


Fig. 3 lateral margin of carapace (dorsal view)

4a. Width of frontal-orbital border not much less than greatest width of carapace; 5 teeth on each anterolateral margin (first tooth sometimes with accessory denticle) (Fig. 4a) . . . . . ?***5***

4b. Width of frontal-orbital border distinctly less than greatest width of carapace; 6 or 7 teeth on each anterolateral margin (Fig. 4b) ***6***

5a. Basal antennal segment with a smooth or granulated ridge (Fig. 5a) . . . . ***Thalamita crenata***

5b. Basal antennal segment with several sharp spines (Fig. 5b) . . . . ***Thalamita spinimana***

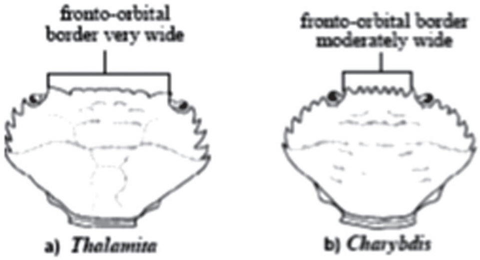


Fig. 4 carapace (dorsal view)

Fig. 5 basal antennal segment

6a. Posterior border of carapace forming an angular junction with posterolateral border (Fig. 6a); merus of cheliped without distal spine on posterior border . . . . . . ***.Charybdis truncate***

6b. Posterior border of carapace forming a curve with posterolateral border (Fig. 6b);merus of cheliped with distal spine on posterior border ***7***

7a. Carapace with distinct ridges or granular patches behind level of last pair of anterolateral teeth (Fig. 7a) . . . . ***.Charybdis natator***

7b. Carapace without distinct ridges or granular patches behind level of last pair of anterolateral teeth (Fig. 7b) ***8***

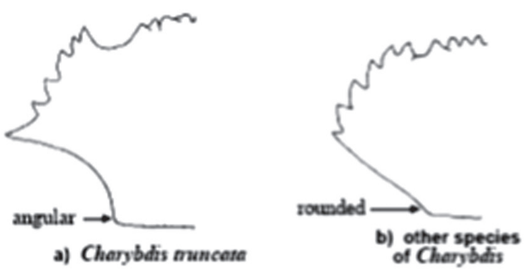


Fig. 6 left side of carapace (dorsal view)

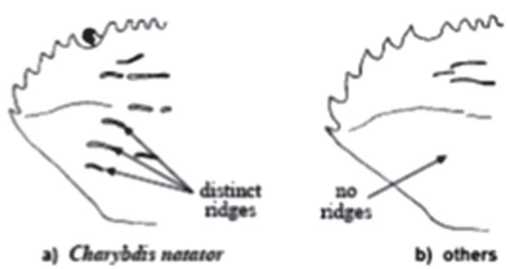


Fig. 7 left side of carapace (dorsal view)

8a. Merus of cheliped with 2 spines on anterior border; palm with 2 spines on upper surface (Fig. 8a) . . . . ***.Charybdis anisodon***

8b. Merus of cheliped with 3 or 4 spines on anterior border; palm with more than 2 spines on upper surface (Fig. 8b) ***9***

9a. First anterolateral tooth not truncate or notched (Fig. 9a) . . . . ***.Charybdis annulata***

9b. First anterolateral tooth truncate or notched (Fig. 9b) **. *10***

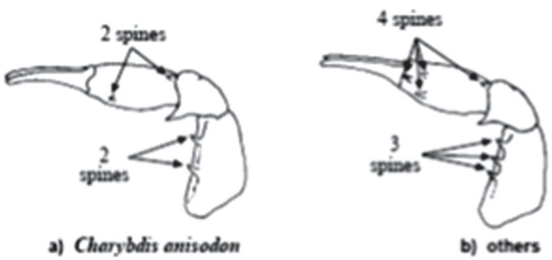


Fig. 8 right cheliped (dorsal view)

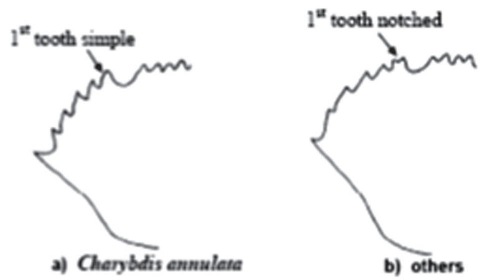


Fig. 9 lateral margin of carapace (dorsal view)

10a. Palm of cheliped with 4 spines on upper surface (Fig. 10a); male abdominal segment 4 keeled (Fig. 11a) **. . . . .*Charybdis feriatus***

10b. Palm of cheliped with 5 spines on upper surface (Fig. 10b); male abdominal segment 4 not keeled (Fig. 11b) **. *11***

Fig. 10 right cheliped (dorsal view)

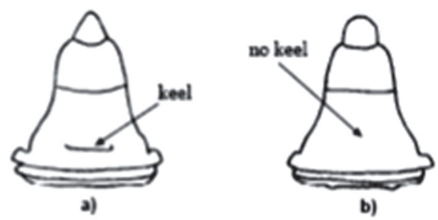


Fig. 11 male abdomen

11a. Palm with well-developed spines (Fig. 12a); male abdominal segment 6 with convex lateral borders (Fig. 13a); last anterolateral tooth smallest and spiniform, not projecting beyond preceding tooth (Fig. 14a) **. . . . .*Charybdis japonica***

11b. Palm with poorly developed spines (Fig. 12b); male abdominal segment 6 with lateral borders parallel in proximal half (Fig. 13b); last anterolateral tooth elongate, projecting laterally beyond preceding tooth (Fig. 14b) **. . . . .*Charybdis affinis***

12a. Last anterolateral tooth subequal in size to others (Fig. 15a) **. . . . .** ?***13***

12b. Last anterolateral tooth at least 2 times larger than others (Fig. 15b) **. *16***

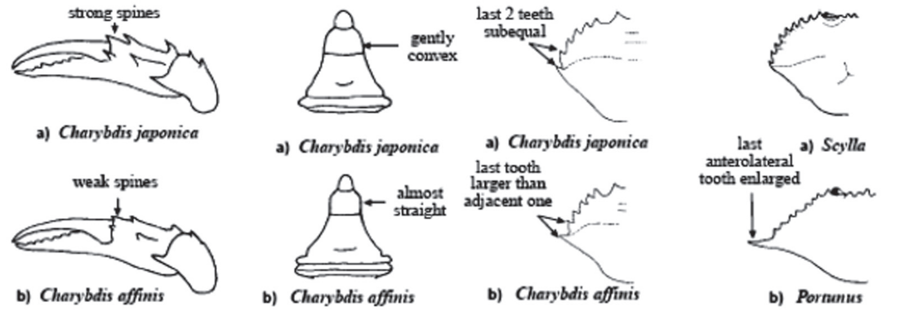


Fig. 12 right cheliped **Fig. 13 male abdomen** **Fig. 14 anterolateral teeth** **Fig. 15 anterolateral teeth**

13a. Carpus of cheliped with only 1 low to very low granule on outer surface, never spiniform (Fig. 16a); colour of palm usually with at least some patches of orange or yellow in life **. . . . *14***

13b. Carpus of cheliped with 2 distinct spiniform or sharp granules or spines on outer surface (Fig. 16b); colour of palm in life green to purple **. *15***

14a. Frontal margin usually with sharp teeth (Fig. 17a); palm usually with distinct, sharp spines (Fig. 18a) **. . . . . *Scylla paramamosain***

14b. Frontal margin usually with rounded teeth (Fig. 17b); palm usually with reduced, blunt spines (Fig. 18b) **. . . . . *Scylla olivacea***

15a. Frontal margin usually with rounded teeth (Fig. 19a); sharp granules on palm and carpus never spiniform; colour in life: carapace usually very dark green to black, outer surface of palm purple and never with marbled pattern, last legs marbled only in males . . . . **. . . . .*Scylla tranquebarica***

15b. Frontal margin usually with sharp teeth (Fig. 19b); sharp granules on palm and carpus often spiniform; colour in life: carapace usually green to olive-green, outer surface of palm green and often with marbled pattern, last legs marbled both in males and females **. . . . . *Scylla serrata***

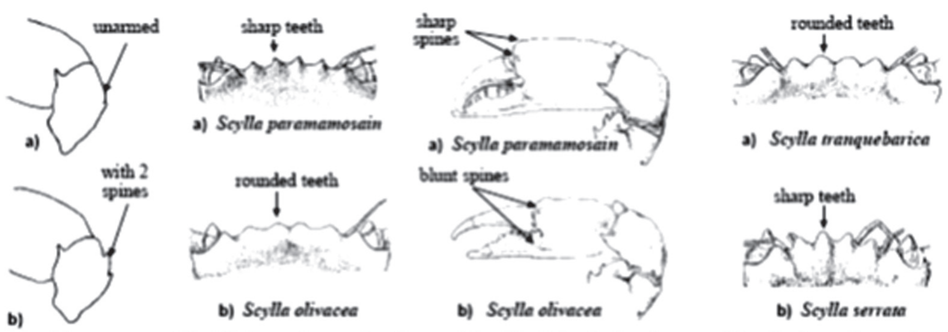


Fig. 16 carpus of cheliped **Fig. 17 frontal margin of carapace (dorsal view)** **Fig. 18 right cheliped** **Fig. 19 frontal margin of carapace (dorsal view)**

16a. Carapace with 3 purple to red spots on posterior half**. . . . .*Portunus sanguinolentus***

16b. Carapace marbled or with uniform coloration **. . . . .**?***17***

17a. Front with 4 teeth (Fig. 21a); inner margin of merus of cheliped with 3 spines (Fig. 22a)

. . . . ***Portunus pelagicus***

17b. Front with 3 teeth (Fig. 21b); inner margin of merus of cheliped with 4 spines (Fig. 22b)

. . . . .Portunus trituberculatus

Key – P.K.L.Ng .1998. FAO species identification guide for fishery purposes – Crabs –Portunidae .

Portunus pelagicus (Linnaeus, 1758) (Flower crab/ Blue Swimming Crab).

Carapace rough to granulose, front with 4 acutely triangular teeth; 9 teeth on each anterolateral margin, the last tooth 2 to 4 times larger than preceding teeth. Chelae elongate in males; larger chela with conical tooth at base of fingers.

Colour: males with blue markings, females dull green/greenish brown.

Portunus sanguinolentus (Herbst, 1783) (Three-spot swimming crab).

Carapace finely granulose, regions just discernible; 9 teeth on each anterolateral margin, the last tooth 2 to 3 times larger than preceding teeth. Chelae elongated in males; larger chela with conical tooth at base of fingers; pollex ridged.

Colour**:** olive to dark green, with 3 prominent maroon to red spots on posterior 1/3 of carapace.

Charybdis feriatus(Linnaeus, 1758) (Crucifix crab)

Carapace ovate; 5 distinct teeth on each anterolateral margin.

Colour: distinctive pattern of longitudinal stripes of maroon and white, usually with distinct white cross on median part of gastric region; legs and pincers with numerous scattered white spots.

Charybdis natator (Herbst, 1789) (Ridged swimmimg crab)

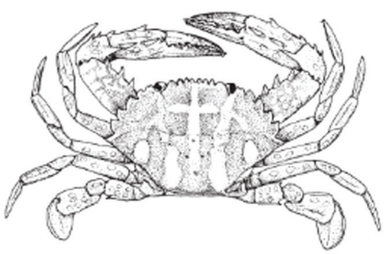
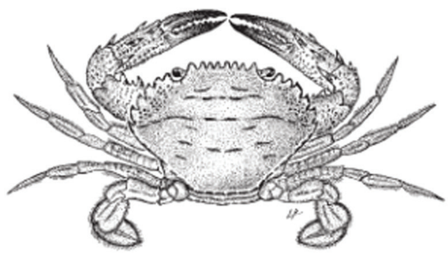
Carapace with densely covered with very short pubescence which is absent on several distinct transverse granulated ridges in anterior half.

Colour: orangish red overall, with ridges on carapace and legs dark reddish brown.

Podophthalmus vigil (Fabricius, 1798)

Carapace distinctly broader than long; anterior margin much broader than posterior margin, with posterolateral margins converging strongly towards narrow posterior carapace margin; orbits very broad. Eyes very long, reaching to or extending beyond edge of carapace.

Colour: carapace green; chelipeds and parts of legs violet to maroon in adults.

Podophthalmus vigil (Fabricius, 1798) **Portunus sanguinolentus** (Herbst, 1783)

Portunus pelagicus (Linnaeus, 1758)

***Scylla* spp.**

The taxonomy of the genus *Scylla* has been terribly confused and is still difficult. Recent research in Australia (Keenan et al., 1998) has clearly shown, using morphological, DNA, and allozyme data, that there are 4 species of *Scylla*.

Scylla serrata (Forsskål, 1775) (Giant mud crab)

Carapace smooth, with strong transverse ridges; H-shaped gastric groove deep; relatively broad frontal lobes, all more or less in line with each other; broad anterolateral teeth, projecting obliquely outwards, colour green to greenish black; legs may be marbled. Well- developed spines present on outer surface of chelipedal carpus and anterior and posterior dorsal parts of palm.

Scylla tranquebarica (Fabricius, 1798) (Purple mud crab)

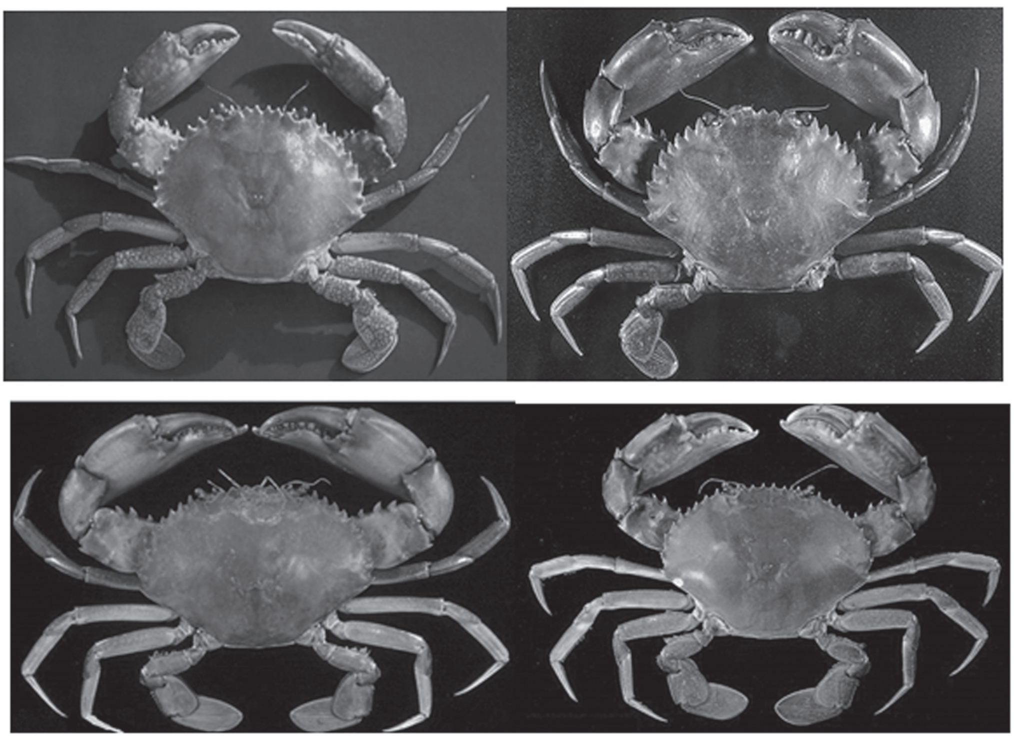
Colour varies from brown to almost black in coloration, and has very well-developed spines on the outer surfaces of the chelipedal carpus and the palm (as seen in *S. serrata*). It differs from *S. serrata*, however, by having the frontal teeth more acutely triangular, the median pair projecting slightly forwards of the lateral pair, and the anterolateral teeth gently curving anteriorly, giving the carapace a less transverse appearance.

Scylla olivacea (Herbst, 1796) (Orange mud crab)

Carapace brownish to brownish green in colour (sometimes orangish), palm orange to yellow. It has a smoother, more evenly convex carapace with very low transverse ridges, a shallow H-shaped gastric groove, the median pair of the frontal lobes more rounded and projecting slightly forwards of the lateral ones, the anterolateral teeth gently curving anteriorly, giving the carapace a less transverse appearance. It also has very low spines on both the outer surface of the chelipedal carpus and the dorsal surface of palm.

Scylla paramamosain Estampador, 1949 (Green mud crab)

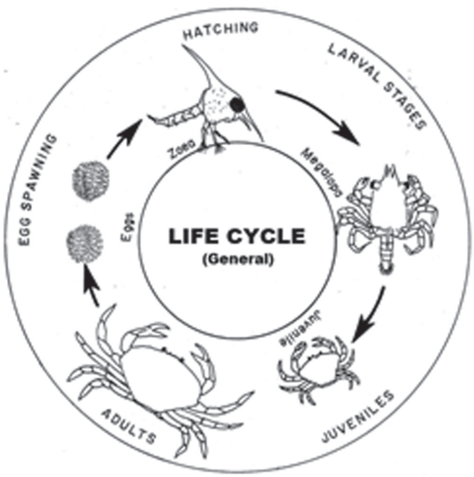
Carapace usually green to light green, palm green to greenish blue with lower surface and base of fingers usually pale yellow to yellowish orange. Frontal margin usually with sharp teeth, palm usually with distinct, sharp spines.

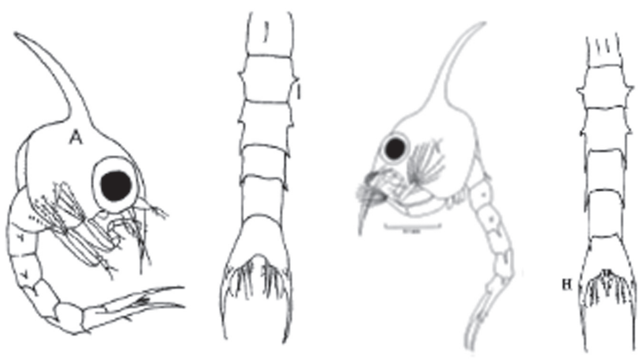


Life cycle & Biology of Portunid crabs

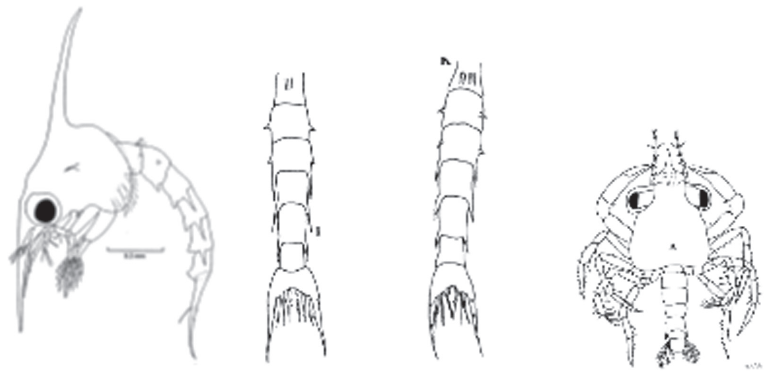
Larval stages

In general, development in almost all crabs is via zoeae. The eggs hatch into first zoeae which typically go through 1–7 instars before becoming a megalopa. The number of zoeal stages varies from species to species.Some species have larger eggs and fewer zoeal stages. Majids in particular, typically have only two zoeal stages. Some groups have species in which the typical number of zoeal stages is reduced, with their zoeae more advanced in form, and having fewer stages. This is termed semi-abbreviated development. In extreme cases, there may only be one zoeal stage that may not even need to feed, relying entirely on stored yolk inside the body. In a few species, the larval development is even more truncated, with no free swimming zoeal stages, and the eggs hatch directly into megalopae, or even the first crab stage, this is abbreviated development. Few marine crabs practice abbreviated development, notable being some species of pilumnids, dromiids, homolodromiids, freshwater sesarmids and all true freshwater crab families.





Zoea-I Zoea-II



A- Carapace, I- Abdominal segment, H- Telson, K- First abdominal segment with spines

***Larval stages of the marine crab, *Portunus pelagicus* (Linnaeus, 1758)**

***** For details refer **Josileen, J**. and N. G. Menon. 2004.

Growth

Crustaceans are equipped with a hard exoskeleton that must be shed in order to grow, i.e., through moulting or ecdysis. Quantifying patterns of crustacean growth is difficult. Although there have been many studies, there is no generally accepted or convincing model describing crustacean growth, which is comparable to the models widely applied to fish growth. Among the reasons for this are the complications of incremental, discontinuous growth by moulting and the variety of life history strategies expressed by crustaceans. The best way of describing the growth of many crustacean species is by observing their moulting pattern. Crustacean growth is dependent upon the duration of the intermoult (moult interval) and size increase at each moult (moult increment). The processes of the moulting cycle have been adequately described by Skinner (1985). The growth of *Portunus pelagicus* from the first instar to stage 16 was studied by rearing the crabs in the laboratory (Josileen and Menon, 2005). The males have grown from an initial average carapace width of 2.38 ± 0.18 mm to 159.86 ± 3.52 mm; i.e. from first instar to sixteenth instar within a mean period of 272 days and further reared to a maximum of 455 days. The average total weight gained was 275.00 ± 25.41 g from an initial weight of 0.008 g. Females have grown from an initial average carapace width of 2.43 ± 0.34 to 154.31 ± 2.73 mm, reached sixteenth instar within a mean period of 332 days. The average weight gain during the same period was 0.006 g to 210.33 ± 18.39 g.

In crabs there are certain morphological features which are present in full expression at sexual maturity. These changes in morphological characters are otherwise known as secondary sexual characters, are prominent in both sexes of the crabs. In males, pubertal changes include the colour of the chelae and other pereiopods, length and depth of the pereiopods, and length of the first pleopods relative to the sternites in the sternal depression. In *P. pelagicus* it was noticed that there is a drastic change in the length of chelae in males by their 12th moult. The total increment was 24.23 mm from the previous moult registering 97.51% increase in chelar propodus length. Chelar propodus depth also increased, 3.68 mm (45.71%), but it was more prominent in the subsequent mature moultings. Male has pleopods modified as copulatory organ on the first and second abdominal somites. Onset of sexual maturity was explicit in female crabs too. In contrast to males, passage of a female through pubertal moult was indicated by gross morphological changes particularly of the abdomen and accessory reproductive structures. The most evident change in the female was the change of the triangular abdomen to oval shaped one and in later moultings it almost attained a semicircular shape. In juveniles, abdomen was held tightly against the sternum and by the puberty moult the abdominal flap become free. All the abdominal segments become freely articulated and bordered by small setae. If the abdomen of the female was lifted, round oviduct openings can be seen which was a slit like in a juvenile crab. There are four pairs of biramous pleopods on the second to fifth abdominal segments and these pleopodal endopodites bear clusters of long and silky setae to which eggs are attached during spawning.

Sexual dimorphism and sexual characters

In crabs, sexes are separate and sexes can be distinguished from the shape of the abdomen. In males the abdomen is narrow, inverted ‘T’ shaped and in addition mature males have larger and broader chelae. The first and second abdominal appendages (pleopods) are highly modified to form an intromittant copulatory organ. Females possess a broad abdomen, conical/oval in shape (according to the stage of maturity) and bear four pairs of pleopods. Many species of crabs show sexual dimorphism, with males being larger, smaller, or possessing special or enlarged structures. In some species the females are the larger. Most commonly, males have proportionately much larger chelipeds or chelae. In some heterochelous crabs, males have one of their chelipeds extremely enlarged to be used for courtship. Males always have only two pairs of gonopods (uniramous swimmerets or pleopods) which are specially modified for copulation (most crabs practice internal fertilisation). The first gonopod (G1) is basically a highly modified pleopod which has been folded or rolled longitudinally to form a cylindrical tube. The degree of this folding varies; from incomplete, leaving a prominent longitudinal gap between the two margins, to having the folds overlapping several times. The channel thus formed can vary from very wide to extremely narrow and almost capillary-like. The form of the G1 varies from broad to very slender, straight to sinuous, and even strongly recurved.

Reproductive system

The male reproductive system of is bilaterally symmetrical creamy to whitish in colour, composed of a pair of testes, a pair of vas differentia, and a pair of ejaculatory ducts internally, and a pair of pleopods externally as accessory reproductive organs, present on the inner side of the abdominal flab. The vas differentia has been divided into three distinct regions, based on the morphological and functional criteria: Anterior (AVD), Median (MVD) and Posterior (PVD) vas deferens. The female reproductive system composed of a pair of ovaries, a pair of seminal receptacles (or) spermatheca, and a pair of oviducts open to the exterior through the female genital opening situated on the left and right sternites of sixth thoracic segment. The ovaries are categorized into five stages, according to the size, colour and external morphology of the ovaries; immature, early maturing, late maturing, ripe and spent. In general males mature earlier than females and the size at first maturity varies from species to species.

Mating and spawning

Mating takes place as soon as the female crab moults with a hard male. The sperms are transferred and stored in the spermathecal of the female crab. After the spawning the eggs are attached to the endopodites of the pleopods and females carry the 'berry' till hatching and release the planktonic larvae (zoeae). The embryonic development takes 8-12 days in tropical species and the period is considerably long in other species. Hatching generally takes place during early morning hours.

Fecundity

Fecundity is an index of reproductive capacity, expressed in terms of the number of eggs produced by an organism. Among decapod crustaceans, fecundity varies widely within families and genera, and in crabs it varies from species to species. There is also variation within the same species, due to factors such as age, size, nourishment, ecological conditions of the habitat, etc. (Giese & Pearse, 1974; Shields, 1991). In general, fecundity in crabs is measured as the number of eggs produced in each clutch, and it is usually described as a function of body size (Corey & Reid, 1991). Fecundity allows a better understanding of the reproductive potential, dynamics and evolution of a given population (García-Montes et al.,1987). Variation in fecundity was primarily a reflection of variation in the size of the crab at maturity. Brachyuran crabs show a great diversity in embryonic development, especially owing to a significant variation in egg size. Fecundity, expressed as average number of eggs in ovigerous females, was positively correlated with the size of the egg-bearing females in all species. The relationship between female size and egg number is usually described as an allometric function equivalent to that between size and weight (Hines, 1988; Josileen 2013). The increase in fecundity is here explained by positive allometric relationship (increase in egg number with the increase in total width). For brachyuran crabs correlation is often high and body size is the prime determinant in fecundity per brood and reproductive output. For example, Josileen (2013) reported that in Portunus pelagicus the fecundity measured ranged between 60,000 and 19,76,398 in crabs with carapace widths of 100 to 190 mm from Indian waters. In same species from Malaysia, fecundity estimates ranged from 1,48,897 to 8,35,401 eggs within a carapace width of 102-140 mm (Arshad et al., 2006).

Food & feeding

Knowledge of the dietary habits of a species is essential for understanding its nutritional requirements and thus its interactions with other groups of animals. Crabs include filter feeders, sand cleansers, mud, plant, and carrion feeders, predators, commensals, and parasites (Dall & Moriarty, 1983). Crabs occupy many different niches and inhabit many different habitats in a variety of geographical areas, and this is reflected in the variety of food consumed by them.

The crab uses its mouthparts to chop the food into small pieces and then the gastric mill ossicles further reduce the food to unidentifiable fragments. The majority of researchers use the foregut contents to study the quantity and nature of the different food items the crab has consumed (Sukumaran & Neelakandan, 1997; Chande & Mgaya, 2004 and Josileen, 2011b). They are all opportunistic omnivores with a preference for animal prey, but within that framework only rarely feed on more mobile prey such as fish and prawns. Josileen (2011b) observed that crustaceans constitute the most favoured item in *Portunus pelagicus* diet, followed by molluscs and fish. Also recorded the presence of detritus (80%) in the stomachs, which suggests that these crabs are also detritivorous, consuming both fresh and decaying flesh of all kinds of animals. It was found that the stomachs of juveniles and sub-adults are predominated by debris. Grapsid, xanthid, majid, potamid, and portunid crabs (in portunids particularly juveniles) have also been reported to consume plant material.

Fishery and Management

Crabs are mainly landed by as a by-catch in trawls all along the coastal states and especially by gillnets in Tamil Nadu which is the major contributor for the crabs in India. From the growth studies conducted in different species of the commercial crabs it is estimated that the life span of these crabs may be around three years, although majority of the crabs is fished in the early part of their life (0-year class), leaving only a few to reach their maximum age. At present there is no separate management guidelines for crabs other than the general trawl ban for the respective states. Minimum Legal Size has been implemented in Kerala (Mohamed et al., 2014) and likely to implement other southern states very soon.

At present, there is no ban on fishing the berried crabs and other than CMFRI is proposing a management plan for Blue Swimming Crab in Palk Bay region of Tamil Nadu. As a conservation measure, fishermen must be educated to release the berried and soft crabs to the sea while they are alive. The state governments should take steps to implement ban during peak spawning seasons to prevent indiscriminate fishing. The best method to ensure a sustainable fishery throughout the year as well as to improve the quality of the yield is to ban fishing and marketing of berried crabs.

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CHAPTER

22

Inshore Shrimps - Diversity and Life History Traits

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India being a tropical country has wide faunal diversity in the marine environment. Some of them form commercial fishery especially from inshore waters for domestic and international markets. The penaeid shrimps are notable among the resources that contribute towards the commercial fishery of the country. In 2017, 209513 t of penaeid shrimps were landed from both inshore and deep sea together. Fishery is mostly by trawlers- multiday which venture out to the sea from three to several days and single day trawlers that return within a day.

Diversity

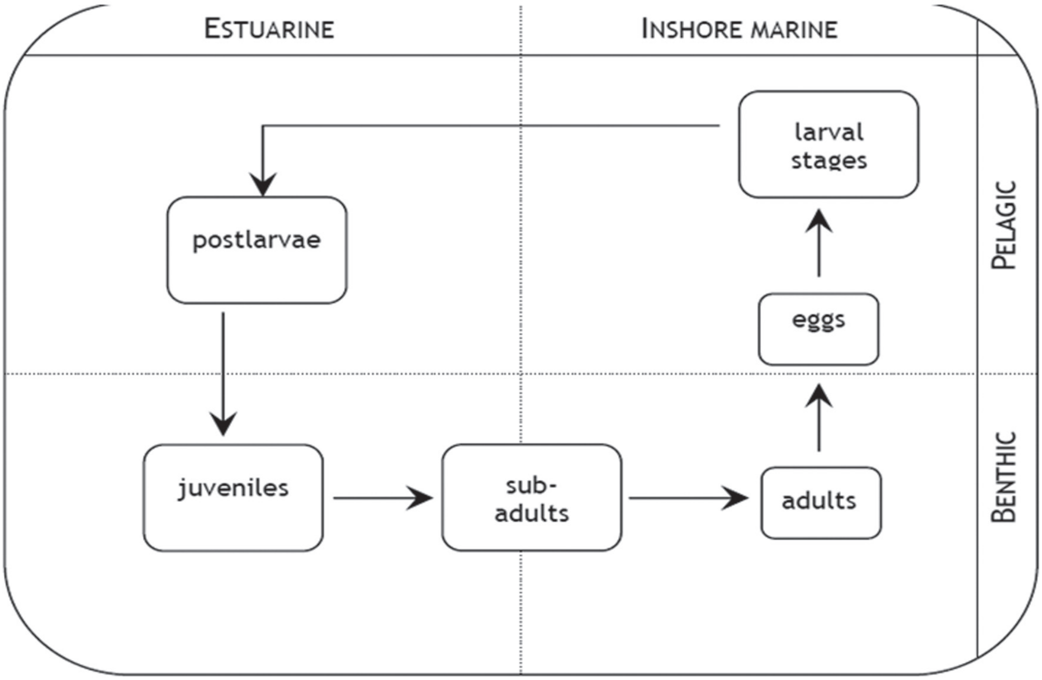
The inshore marine waters are inhabited by shrimps belonging to different family main being penaeidae and sergestidae. There are more than 70 species of penaeid shrimps recorded from the Indian coast among which the species belonging to the genera *Metapenaeus, Penaeus* and *Parapenaeopsis* are of economic importance. The penaeid shrimps that occur in commercial fishery are mainly *Metapenaeus dobsoni, Metapenaeus monoceros, Metapenaeus affinis*, *Parapenaeopsis stylifera*, *Penaeus monodon*, *Penaeus indicus, Penaeus merguiensis, Penaeus pencillatus, Penaeus semisulcatus, Penaeus latisulcatus, Penaeus canaliculatus, Penaeus japonicus*, *Metapenaeus brevicornis, Parapenaeopsis sculptilis, Parapenaeopsis hardwickii, Parapenaeopsis cornuta, Metapenaeus kutchensis* etc. Species belonging to the genera *Metapenaeopsis*, *Solenocera*, *Trachypenaeus* and *Megokris* form minor fishery. Besides these *Acetes* spp of the sergestidae family are distributed throughout the Indian coast forming a fishery in the northwest coast of India.

Life history

Penaeid shrimps may be burrowing or wandering in nature. Wandering species like *P.merguiensis* and *P.indicus* generally spawn at a depth of 7–30 m in offshore waters, usually near the nursery ground. The larvae spend part of their life cycle in nursery ground until adolescent stage when they start migrating to deeper and more saline waters.

The burrowers like *P. monodon* show marked nocturnal activity, burrowing into the bottom substratum during the day and emerging at night to search for food. This diurnal activity is closely associated with changes in light intensity but may also be due to other factors.

In penaeid shrimps the location of the spawning grounds in respect of depth or distance from the coast seems to vary with the adult size and habits of parents. Small species like *M dobsoni, P.stylifera* which shoal comparatively in shallow coastal waters also spawn there. Eggs and larvae of both species have been collected in large numbers up to about 12-13 fathoms, beyond this they are few and are seldom present in offshore plankton. The eggs of penaeid shrimps are demersal. The nauplii hatching out of these eggs, soon rise to the surface and are planktonic in habit. The first larval stage is termed nauplii, are free swimming. These do not feed and passes through different moult stages. The next stages are protozoea, mysis and early post larvae which are also planktonic and carried towards the shore by tidal currents. After the PL6 stage they change to benthic habit. The penaeid shrimps are generally preyed upon by the demersal fishes of the area where they exist.



Species like *P. stylifera* do not have an estuarine phase, but is believed to migrate within the sea from coastal to deeper waters during July-August. Shoreward migration is during October as after the southwest monsoon they are caught from this month onwards. It is found in large shoals in the shallow waters and is an important species in inshore and offshore fishery.

Penaeid shrimps are heterosexual (petasma in male and thelycum in female). Males are usually smaller than females. The endopodites of the first pair of pleopods are modified as petasma in males. The thelycum is located on the ventral part of the thorax between the last three pairs of the thoracic legs. In males the opening of the genital duct is on the last pair of pereiopods and in females it is situated on the bases of the coxae of the third pair of pereiopods. They spawn throughout the year with spawning peaks which may change based on the environmental conditions. Fertilisation is external. The eggs are shed in water and the larvae are planktonic. The adults do not care for the eggs or young ones.

There are five maturity stages recognised in penaeid shrimps- immature, early maturing, late maturing, mature and spent. They are carnivorous in their feeding habit. Fecundity is high, varies with species, size of ovary and size of female. Their life span is usually between 2 to 2.5 years.

M. dobsoni matures at around 64-66 mm total length. Fecundity ranges from 35,000 to 1,59,000. The ova diameter measure from 0.35 to 0.44 mm (90 to 125 mm total length). Largest female measured

130 mm and male 125 mm total length in the fishery. Their gut content mostly consisted of crustacean remains and digested matter.

P. stylifera females mature at around 71 mm total length. They produce 35,000 to 2,39,00 eggs based on their length (88 to 115 mm total length). Largest females measure 125 mm total length and males 120 mm in total length.

P. indicus matures at around 120 mm total length. Their gut content consisted of digested matter, crustacean remains, bivalve shells and fish scales.

P. monodon females mature between 196-200 mm total length. Fecundity range from 5,00,000 to 7,50,000. The gut content consisted of crustacean appendages, digested matter.

M. monoceros females mature at around 114 mm total length. The mature ova are opaque, measure between 0.14 and 0.26 mm with majority of them in the range of 0.17 and 0.23 mm. Their fecundity ranged from 49,000 to 3, 90,000.

S. crassicornis females mature at around 60-65 mm total length. Fecundity ranged from 28,000 to 1,00,00 (61 to 102 mm total length).

S. choprai females mature at around 66.5 mm total length. Mature ova diameter ranged from 0.24 to 0.35 mm.

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CHAPTER

23

Integrative Taxonomy - A Novel Approach to Biological Studies

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Taxonomy is the discipline of Biology that identifies, names and classifies organisms according to certain rules. Taxonomists are scientists who study classifying and taxon (taxa-plural) is a category into which related organisms are placed. Aristotle was the first taxonomist dividing organisms into land, sea and air dwellers and Linnaeus introduced the binomial nomenclature (Genus and species) where the genus is always capitalized followed by species in lower case. Taxonomy is central to exploring and understanding biodiversity. Alpha taxonomy deals with the species category, beta taxonomy with higher categories. The need for good alpha taxonomy is further increased by the biodiversity crisis both for assisting conservation programs and documenting diversity before it is lost.

Reasons to Classify

- Shows evolutionary relationships
- Accurately & uniformly names organisms
- Prevents misnomers such as starfish & jellyfish that aren't really fish
- Uses same language (Latin) for all names
- Prevents duplicated names because all names must be approved by International Naming Congresses (International Zoological Congress)
- Naming rules are followed called the International Code for Binomial Nomenclature

Integrative Taxonomy

A multisource approach that takes advantage of complementarity among disciplines, i.e., fields of study, has been called combined, mul-tidisciplinary, multidimensional, collaborative, or integrative taxonomy mainly focusing on the species level. Integrative taxonomy does not replace traditional taxonomy. Rather, it compresses the traditional but slow taxonomic routine of visiting a taxonomic problem repeatedly into one procedure by coordinating the findings of different disciplines under the procedure. By doing so, integrative taxonomy improves rigor, more confidence in taxonomic information and consequently provides taxonomic stability.

DNA barcoding, a new method for the quick identification of any species based on extracting a DNA sequence from a tiny tissue sample of any organism, is now being applied to taxa across the tree of life. As a research tool for taxonomists, DNA barcoding assists in identifi cation by expanding the ability to diagnose species by including all life history stages of an organism. As a biodiversity discovery tool, DNA barcoding helps to flag species that are potentially new to science. As a biological tool, DNA barcoding is being used to address fundamental ecological and evolutionary questions, such as how species in plant communities are assembled. The process of DNA barcoding entails two basic steps: (1) building the DNA barcode library of known species and (2) matching the barcode sequence of the unknown sample against the barcode library for identification. Although DNA barcoding as a methodology has been in use for less than a decade, it has grown exponentially in terms of the number of sequences generated as barcodes as well as its applications. Detailed species and larval level identification forms the pre-requisite for the proper conservation and management of the declining deep water shrimp resource of the country. DNA barcoding has been successfully used for species identification and discovery of new species, utilizing 650 base pair fragment of the mitochondrial gene, cytochrome oxidase subunit I (COI). COI was effectively used for the discrimination of closely related species and detection of cryptic species as well as for the identification of fish products. Mitochondrial DNA (Mt-DNA) sequence information has been used as an accurate and automated species identification tool for carrying out studies in a wide range of animal taxa, due to the presence of a significant amount of information.

Materials and methods

2.1. Sample collection

(a) Proper disposable or easily sterilized tools. (b) Proper individual storage containers for the organisms and tissues. (c) Data collection tools to handle specimens, tissues. (d) Photo documentation materials (digital camera with appropriate lens(es), memory cards, backup hard drives).

2.2. Storage buffers

(a) Dry ice and cooler. (b) Salt solution. (c) EtOH—95% (nondenatured). (d) Formalin or other voucher specimen preservation solution(s)

2.3. Extraction components

(a) Lysis buffer for extraction method. (b) Proper plates, tubes or storage vessels. (c) When possible, on-site portable DNA extractor.

2.4. PCR components

(a) PCR reaction ingredients and primers . (b) Positive control 16S or 18S and COI

2.5. Sequencing, data QC, and analysis.

Data analysis

Molecular sequences were checked and confirmed using ABI SeqEditor v.1.0. Protein coding gene sequences (COI and Cytb) were translated into amino acids using Transeq (EMBOSS online tool) to avoid the inclusion of pseudogenes. All the sequences were blasted to report GenBank data to verify the potential contamination and the nucleotide sequences were aligned using the Clustal W algorithm. The aligned data was edited using bioedit V.7.0.5.2, gaps of sequences treated as missing data. All the sequences were submitted to GenBank. The pairwise genetic distance was calculated using MEGA 6.0.

Morphological analysis

In case of deepsea penaeid shrimps ancestral state reconstruction (ASR) was used to evaluate character evolutions. Fifty-two morphological characters (24 binary, 27 multistate and one non-informative) were chosen and considered for phylogenetic analyses based on the original taxonomic works of Ramadan (1938), *Crosnier (1978; 1985), Pérez-Farfante (1997) and Dall (1999). All these major characters were re-examined carefully. The data matrix was analyzed with maximum parsimony using combinations of programs: Mesquite v.3.01 (*Maddison and Maddison 2015) *and* PAUP v.4.0 (Swofford 2002). These characters were given equal weightage and unordered, the code given for each state (i.e., 0, 1, 2, 3, and 4). Branch support was assessed using 1000 bootstrap replicates without any outgroups. Results acquired from both morphological and molecular tools was combinedly assessed before deriving to any conclusion of a particular species, which is nothing but integrative taxonomy.

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CHAPTER

24

Introduction to Geostatistics

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Geographical Information System (GIS) is a technological tool used to describe and characterize spatially referenced geographical information for the purpose of visualizing, querying and analyzing. The tool enables capturing, storing, analyzing, sharing, displaying and modelling of spatial data maintained with in single database. Making decision based on geography is basics to human thinking and spatial analysis using GIS enable people to combine information from many independent sources and derive entirely new layers of information that are more accurate and reliable in decision making. Spatial analysis involves study of phenomenon that varies with time and space. Geostatistics is a branch of statistics used for analysis of spatial or spatiotemporal data set by applying sophisticated set of various statistical and probabilistic models. Here, we estimate the value of phenomenon from unknown location where no measurements are available with the help of direct measurements derived from known locations. GIS has emerged as powerful tool in the recent years by providing various geospatial solutions in urban planning, mining, natural resource evaluation and management, pollution estimation, risk assessment and large scale mapping thus becoming integral tool in our day today life.

1. Data for GIS

Data for GIS are obtained from various sources like aerial & satellite imageries, digital data, conventional maps, census, meteorological department, field data (surveys/GPS) etc. The information obtained can be classified into types of database: - spatial data which describe the location (where the object is?) and attribute data which characterize the location (what the object is? or how much the object is?)

1.1. Spatial Database:

Spatial data is representation of complex real world in a simplified manner. Here the geographical features are represented by three basic types- points, lines and area. *Points* represent dimensionless features such as wells, post box, tube well etc. that are very small and their location can be explained by only coordinate's values. Lines depict features with length, such as roads, railways stations, administrative and international boundaries etc and are two-dimensional. Area or polygons are used to represent three-dimensional objects that have height, width and length such as agriculture lands, water bodies, forest areas and administrative areas.

1.2. Attribute database:

Attribute data depicts various characteristics of different object / features on earth surface. This can of qualitative types like land use type, soil type, name of the city/river etc.) or of quantitative types (like elevation, temperature, pressure of a particular place, crop yield per acre etc.). Thus, attribute data can be both numeric and textual.

2. Representation of Database:

The way that location is represented in a geodatabase can be either a raster or a vector position.

2.1. Raster data

A raster based format uses imaginary grid of cells or matrix to displays, locates and stores graphical data. The fundamental unit of raster system is pixel. Here, the whole study area is divided into uniform rows and columns and each cell or pixel is used for storing point, line or area entities. Here, points are represented by individual column/ row entities, lines are depicted by connecting the adjacent cells or pixels and areas are stored as set of contiguous cells defining the interior. The accuracy of raster data formats depends on pixel or grid size and may vary from submeter to kilometres. Layers are functionally related map features that are used to represent different two-dimensional features on map. Different layers are used to in GIS for storing various unique information such as forest cover, soil types, land use pattern and wetlands. Satellite images, Digital terrain models (DTM) and digital elevation models (DEM) are examples of raster data (Koeln *et al* 1994 and Huxhold 1991). Raster data formats require less processing over vector formats but they consumes more computer space for storing of data.

2.2. Vector data

In vector maps, world is represented by points, lines and polygons. The fundamental unit of vector system is point. Lines are set of mathematically connected points and area are represented by set of mathematically connected coordinates or lines joined together to form polygons which define the boundary of area. Unlike raster images, vector images can be of high resolution. Vector data requires less computer storage space and maintaining topological relationships is easier in this system (Koeln et al 1994; and Huxhold 1991).

3. Projections

Once the spatial data have been collected, the data needs to be in same coordinate system for display and analysis. As earth surface is ellipsoidal therefore set of set of systematic mathematical transformation is needed to display earth's latitude and longitude onto a plane.

Projection is a method by which curved surface of the earth is portrayed on a flat surface. Initially the earth was thought to be flat surface but later on it was proven that earth is an ellipsoidal/ spheroid, the circumference of the earth is about 1/300th smaller around the poles *vs* equator. This difference in distance around the poles and equator use to cause error in the readings and to rectify the errors different projection systems were created. These are just different measurements of the "flattening" at the poles The different projection systems are helpful in measuring and preserving one or more properties such as area, shape, direction or distance over commonly used latitude longitude (x, y, which measures in degree and not in distance) coordinate system.

3.1 Different types of projections:

Azimuthal or planner projection: Projection surface laid flat against the earth.

Conic- Cone is placed on or through the surface of earth.

Cylindrical- projection surface wrapped around the earth.

Coordinate system: A reference framework consisting of set of points that are used to define its position in space either in two or three dimensions.

Cartesian Coordinate system: Two dimensional, planner coordinates system in which the horizontal distance is measures along the x axis and vertical distance is measures along the y axis. Each point ids are defined by x, y coordinate.

Datum: Set of coordinates that measures the position on a surface using x,y coordinates (horizontal) and height above or below the surface (vertical datum).

Geocentric datum: A horizontal geodetic datum based on a ellipsoidal that has its origin at the earth centre's mass and measures coordinate of every point on Earth using latitude longitude and height above its surface. Ex. World Geodetic system of 1984. (WSG84)

3.2 Common GIS projections:

***Mercator* :** It is cylindrical projection tangent to the equator of earth. Preserves the local shapes and display accurate compass bearing for sea travel.

Transverse Mercator: It is also a type of cylindrical projection similar to Mercator except the cylinder is tangent along a meridian instead of the equator. It minimizes the distortion along north-south line, but does not maintain true direction.

Universal Transverse Mercator (UTM): *UTM is* based on transverse Mercator projection and divides the whole world in 60 north south zones, each zone having a width of 6^o longitude. Each zone is numbered consecutively beginning with zone one covering longitude 180^o to 174^o West and progressing east word to zone 60, between 174^o to 180^o East longitude.

Lambert Conformal Conic – A conic, conformal projection typically intersecting parallels of latitude, standard parallels, in the northern hemisphere. This projection is one of the best for middle latitudes because distortion is lowest in the band between the standard parallels. It portrays shape more accurately than area.

Most commonly used projection in GIS is UTM or the preference may change depending on the area of interest.

4. Interpolation

Spatial data is important in making important decisions in natural resource management. Collection of spatially continuous data is often difficult and expensive. Most of the data collected by field surveys will be typically from point sources. But scientists and managers requires accurate spatial continuous data to make justified interpretations.

Spatial continuous data of environmental variables are in demand in the geographic information systems (GIS) and modelling techniques for studying the ecology and biological conservation (Collins and Bolstad, 1996; Hartkamp et al., 1999). Thus, spatial interpolation methods have overarching importance in converting point data in to spatially continuous data. Interpolation methods can fall under two categories 1. Global methods and 2. Local methods. Global methods use all available data of the region of interest to derive the estimation and capture the general trend. Local methods operate within a small area around the point being estimated (i.e., use samples within a search window) and capture the local or short-range variation (Burrough and McDonnell, 1998).

4.1. Global interpolators

4.1.1 Regression Models

Regression interpolation is using a linear regression model (LM) as interpolator and assumes that the data are independent of each other, normally distributed and homogeneous in variance. Regression methods explore a possible functional relationship between the primary variable and explanatory variables that are easy to measure (Burrough and McDonnell, 1998). The final model can be selected by a thorough understanding of the relationships between the primary variable and secondary variables and/or by Akaike information criteria (AIC) or Bayesian information criteria (BIC) methods.

4.1.2 Trend surface models

An inexact method, trend surface analysis approximates points with known values with a polynomial equation. This is similar to the regression model but uses only geographic coordinates as indirect variables for prediction of the primary response variable (Collins and Bolstead, 1996).

4.2 Local interpolators

4.2.1 Nearest Neighbours (NN)

The nearest neighbours (NN) method draws perpendicular bisectors between sample points (n), predicting the values at the unsampled regions. The resultant polygons are called as Thiessen or Voronoi polygons. All the area inside each polygon will have same value, which is the value of the midpoint of the polygon.

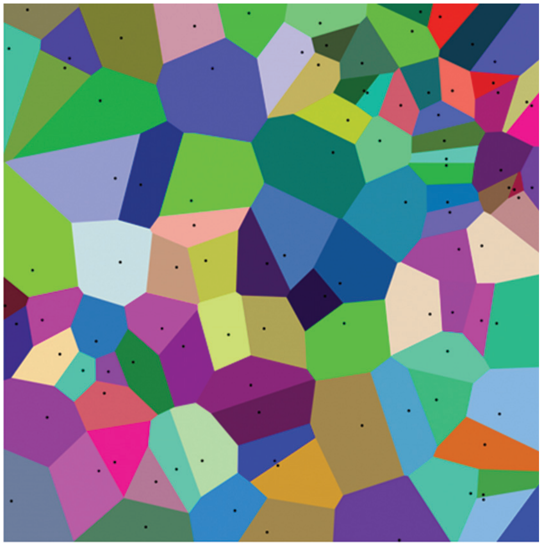

Fig. 1. A Voronoi Polygon map

4.2.2 Triangular Irregular Network

In the triangular irregular network (TIN), all sampled points are joined into a series of triangles based on a Delauney's triangulation. It forms a different basis for making estimates in comparison with those used in NN. The value of the regions falling in a triangle is estimated by linear or cubic polynomial interpolation. Peuker et al (1978) developed the method for digital elevation modelling (DEM) that avoids repetitions of the altitude matrix in the grid system.

4.2.3 Natural Neighbours

The natural neighbours (NaN) method combines many characters of NN and TIN. The method was developed by Sibson (1981). The first step is a triangulation of the data by Delauney's method, in which the apices of the triangles are the sample points in adjacent Thiessen polygons. This triangulation is unique Spatial Interpolation Methods 7 except where the data are on a regular rectangular grid. To estimate the value of a point, it is inserted into the tessellation and then its value is determined by sample points within its bounding polygons. For each neighbour, the area of the portion of its original polygon that became incorporated in the tile of the new point is calculated. These areas are scaled to sum to 1 and are used as weights for the corresponding samples (Webster and Oliver, 2001).

4.2.4 Inverse Distance Weighting

The inverse distance weighting (IDW) method estimates the values of the unsampled points using a linear combination of values of the sampled points weighted by an inverse function of the distance from the said point to the sampled points. The weight diminishes by an inverse factor and sampled points will have more influence on nearby points. The rate of diminishing value depends on the factor (Isaaks and Srivastava, 1989). The weights can be expressed as:

$$\lambda_i = \frac{1/d_i^p}{\sum_{i=1}^{n} 1/d_i^p}$$

where di is the distance between point of interest x0 and sampled point xi, p is a power parameter, and n stands for the number of sampled points used for the estimation. The power parameter is arbitrary decided by the validation at field. Most popular value for p is 2 and then the IDW is called as Inverse square or inverse distance squared (IDS) method.

4.2.5 Splines

This is an Inexact, gradual interpolation which uses piecewise polynomial equation as interpolator. The polynomials describe pieces of a line or surface (i.e., they are fitted to a small number of data points exactly) and are fitted together so that they join smoothly (Burrough and McDonnell, 1998; Webster and Oliver, 2001). For degree p = 1, 2, or 3, a spline is called linear, quadratic or cubic respectively. Typically, the splines are of degree 3 and they are cubic splines (Webster and Oliver, 2001).

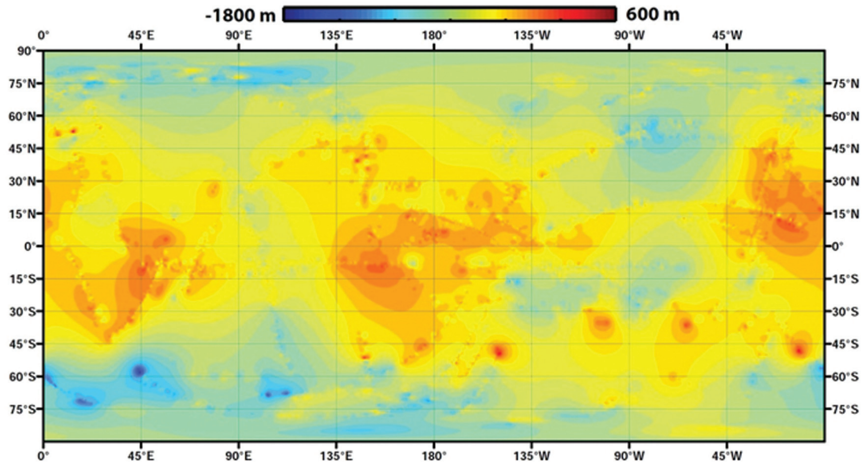

Fig. NASA's Cassini spacecraft gridded elevation data has been splined create the first global topographic map of Saturn's moon Titan [Image credit: NASA/JPL-Caltech/ASI/JHUAPL/Cornell/Weizmann]

4.2.6 Krigging

Basic concept of Geostatistics is that variables of a specific geographic region tend to have a particular structure. Though this particular domain of spatial interpolation has its origin in 1910s in agronomy (Webster and Oliver, 2001), this is mostly developed in the works of geology and mining by Krige (1951). Geostatistics includes several methods that use kriging algorithms for estimating continuous attributes. Kriging is a generic name for a family of generalised least-squares regression algorithms, used in recognition of the pioneering work of Danie Krige (1951). Li and Heap (2008) gives a good review of all the available interpolation methods. In Krigging interpolation is performed by modelling a Gaussian process which considers method of interpolation for which the interpolated values are modeled by a Gaussian process governed by prior assumptions and gives the best unbiased estimate of the unsampled values.

CHAPTER 25

Introduction to Primer and Statistical Methods in Ecological Data Analysis

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Introduction

Although analytical methods in statistics have all along been generic and evolutionary in the first half of past century, the developments happening in the field of computational statistics in the past couple of decades are more need based and custom tuned. A lot of effort is being put in by researchers in bundling methods, theory and procedures in classical statistical literature on their common applicability to a targeted exploration. It is common place to collate various univariate, multivariate, parametric, non-parametric, frequentist and non-frequentist methods, which have applications in different domains like ecology, clinical trials, bioinformatics etc. and tag them as per the domain subject matter. Thus the generic and specific procedures which are of relevance in exploratory and confirmatory analyses in the field of ecological studies of communities have been grouped under a common pivot. During the course of this discussion a couple of such statistical methods used in community structure studies would be dwelled upon.

On the ecological datasets

The typical community structure dataset would have either or both the tags, viz. temporal and spatial. The data could have been collated over multiple sampling spots in a region and also over a period of time. This makes these data to be looked upon from the time series as well as space-series points of view. And another ubiquitous feature of such datasets are their being multivariate. Communities, comprising many species at various levels of abundance, are always recorded as n-tuples at each sampling session and hence are multivariate at core. Although there are possibilities of isolating responses and causes from the bunch and possible univariate procedures could be applied upon, thereafter.

Multivariate tools

Analysis of ecological data involves almost the entire gamut of multivariate data analytical tools. The pivot based (could be labelled region or cluster) comparison of the community abundance has its roots in Hotelling's T square(d) thereafter raising to the multiple comparisons using MANOVA using Wilk's Lambda, Pillai's trace etc. Needless to add, a set of single response multiple regression analysis and univariate ANOVA get subsumed in the multivariate projection and analysis. The common thread in most of these analyses is the polarization of near independent components which have a telling impact on the response variables or the system tracking as a whole.

Another important area in multivariate analysis is the clustering and discrimination domain. The basic thrust in this sector is about measuring the closeness or remoteness of the multiple streaks of expressions of communities, which then gets utilized in grouping or clustering the similarly placed or paced dynamics or also for contrasting the most orthogonal or independent of bunches of variables which could sufficiently project the overall variability in the system. In a way these types of procedures aim at reducing the dimensionality of the bouquet of variables in such a way that inferences and depictions of scenario can be made with two or three dimensional projections. The community datasets often indicate similarity in pattern amongst their subsets, which when zoomed in would yield more interesting bio-climatic cause- effect mechanisms. Tools like Principal Component Analysis (PCA), ordinations by Principal Coordinate Analysis (PCoA) and Redundancy Analysis fall broadly under this conceptualization. Of this the RDA can be viewed as the multivariate extrapolation of univariate multiple regression analysis and it yields the proportion of variance of a set of variables that could be explained by a set of causative factors. PCoA has its action rooting on the distances (preferably Euclidean) between the multi-dimensional points and routing a starting point with its nearest neighbor in as much less a dimension possible so that the resultant scatter of these points clearly shows clusters based on which further PCA type recasting can be done. This is otherwise referred to as Multi-Dimensional Scaling (MDS), the metric variant of it. Also in the context of abundance of communities datasets, the dissimilarities (distances) between the observations can be estimated more nonparametrically (with less leanings on the traditional orthodox assumptions on the values thrown out by the study variables, aka distribution) by using a “Stress” reducing monotonic transformation which simultaneously takes care of point-point contrast as well as distances between the realized observations.

The major bottleneck or invisible opportunity with ecological datasets is that they are counts based with a large possibility of null entries. Also, at times the community sampling boils down to presence or absence type of information. Hence under these circumstances parametric exploration and testing on orthodox moulds would be highly inefficient and error prone. Hence a whole lot of quasi parametric or non-parametric tools have been conceptualized by resonating or tweaking the existing parametric options. One such set of tools is available in the Plymouth Routine In Multivariate Ecological Research (PRIMER).

PRIMER- a curtain raiser

The methods employed by the routines can be broadly categorized into three groups.

(i) Univariate methods:

These are the much focused and widely practiced statistical tools which have been well documented. But in face of multiple causes and effects warranting attention, these single dimensional phenomena need proper justification at the initial stages. Once we start employing these methods, what we involuntarily commit is the fact that the variables under focus are relatively independent of any other factor of co- existence. For example when we study the abundance of a species of fish in isolation it has the inseparable assumption that the influence of other species of fish on the species under focus has been negligible. Hence these set of tools need a very crucial decision to be made even before venturing into data preparation. One of the justifiable usages of these techniques is the calculation and comparison of various indices like species diversity index which might be some measure of the numbers of different species for a fixed number of individuals (species richness). Another similar univariate measure is the biodiversity index which measures the degree to which species or organisms in a sample are taxonomically or phylogenetically relate to each other. Another scenario which can be fitted into the univariate mode is while studying the response of single taxon indicator species to particular environmental gradient.

(ii) Distributional techniques:

In exploratory statistical tools plotting of summary data assumes immense value, especially when very less is known of the variable under study. These contrast from the univariate methods on the count that multiple streams of data can be processed simultaneously. One good example would be the case of plotting counts of species from samples converted into percentage abundance relative to total number of individuals in the sample, and plot the cumulated percentages against the rank of the species. Another useful application of this group of applications is plotting the number of species falling in different abundance ranges against geometrically scaled abundance classes. Here the emphasis is more on the simultaneous depiction of summary values of more than one variable at a time.

(iii) Multivariate methods:

Statistically placing, multivariate techniques deal with summarizing and inferring with more than one variable being considered simultaneously. To put in terms of marine researchers it amounts to something like comparing two samples taken at two different time intervals or two locations on the extent to which these samples share particular communalities like species. The measure of likeness or unlikeness leads to a measure of similarity/ dissimilarity calculated between pair of samples. These types of similarity coefficients lead to classification or clustering of the samples as well as ordination plot in which the samples are mapped in such a way that the distances between pairs of samples reflect their relative dissimilarity of species composition. In other words the manifestations expressed in terms of multiple dimensions have been reduced to singular values which can be ranked. PRIMER provides operations based on these lines like hierarchical clustering, multi dimensional scaling and principal components analysis.

Let us have a peek preview of these methods by way of focusing one module under each one of them.

(i) Univariate Techniques:

Under the univariate setup discussed in detail earlier there are different stages at which the tools can be applied. Let us focus on the determination of stress levels. Let us explore the case of average taxonomic diversity. Species richness (S) is a measure which either can be simply defined as the total number of species present or some adjusted form which attempts to allow for differing numbers of individuals. These species richness indicators form the essential part of diversity indices which give an overall view of multi- species, multi-locational data into a single index. The other aspect of standardizing samples of multi- species data is a measure of their evenness. For example if two samples comprising 100 individuals and four species had abundances of 25,25,25,25 and 97,1,1,1, it is obvious to state that the latter sample lacked evenness. Evenness can be worked out as the function of diversity index (Shannon's index) and the species richness. Though S has been an accepted index of richness of species, it has got its dose of disadvantages too, A few reasons are as follows:

a) The observed richness is too dependent on the sample

b) Species richness has no direct reflection of the phylogenetic diversity

c) Statistically the test on departure of the diversity from expected values doesn't exist.

d) Another interesting feature of richness which attributes to its disadvantage is the fact that its response to environmental annihilations is not unidirectionally correlated.

Towards addressing these problems pairing of the species abundance along with a measure of taxonomic distances was suggested by Warwick and Clarke (1995). As per that approach the taxonomic distances are standardized by the number of steps to be covered in the tree of Linnaean classification. Suppose the species belong to the same family, the steps may comprise the immediate genus of first species and then to the family and then to the genus of the second species before reaching the species itself. The maximum number of steps to be taken is equated to 100 and all the pairwise distances between the species are recalculated to match the standardized longest distance.

(ii) Distributional Techniques:

One of the major challenges facing researchers dealing with marine ecological studies is the issue of discriminating locations or sites is by comparing the data summaries on equal footing. A classical tool in statistics for this situation would be testing the null hypothesis that two or more sites (or conditions) have the same curvilinear (pattern) structure. The easiest method to effect the testing would be to perform Analysis of Variance (ANOVA). But as is known very well, ANOVA in the classical sense has more stringent assumptions about the population and the distribution. Hence if the same were to be performed on variables like Bray-Curtis similarity which have less to resemble the sample means of ANOVA concept. There range is limited and they are proportions and hence have less to do to fulfill the normality assumptions. Hence for such ordination methods the classically rooted univariate ANOVA methods and their multivariate extension MANOVA will stand less chance of justification. A valid test for such situations should be built on a simple non-parametric permutation procedure, applied to the similarity matrix underlying the ordination or classification of samples. Hence PRIMER propounds an analogous test termed as Analysis of Similarities (ANOSIM) to face such multiple comparison problems. The cue is taken from the basic methodology wherein the between categories variation is measured against within categories variation (the one which cannot be explained more). The null hypothesis (H0) is that there are no differences in community composition at different sites (if we consider a study involving samples from different locations). The null hypothesis is examined in the following steps:

(i) The test statistic (a function involving sample observations) is computed reflecting the observed differences between sites, contrasted with the differences among replicates within sites. Using any typical methodology the distances between samples can be computed (viz Bray- Curtis similarity or MDS distance). The ideal test would then be based on the average distance between pairs corresponding to different sites and those within the sites. If $\bar{r}_W$ is defined as the average of all rank similarities among replicates within sites and $\bar{r}_B$ is the average of rank similarities arising from all pairs of replicates between different sites, then a suitable test statistic is

$$R = \frac{(\bar{r}_B - \bar{r}_W)}{0.5 * M}$$

where M=n(n-1)/2 and n is the total number of samples under consideration. It has to be noted that the highest similarity corresponds to a rank of 1 (the lowest value), following the usual mathematical convention for assigning ranks. The denominator, M/2 ensures that R can never lie outside the range (-1,1). It also ensures that R will take the value unity only if all replicates within the site are more similar to each other than any from other sites. R will become zero only when the similarities between and within the sites will be same on average. R can seldom take sub-zero values as that may imply that the similarities between locations is far higher than those within the locations.

(ii) Once the R statistic is computed it is recomputed many times for creating a distribution of the same. This is done as R does not fall under the classical mould of a sample statistic with a well-defined sampling distribution. The samples and the replicates are permuted and the R statistic is recalculated for each permutation. The rationale for this test is if the null hypothesis were to be true that will mean that there will be little effect on average to the value of R if the labels identifying which replicates belong to which sites are arbitrarily rearranged. In general there would be (kn)!/[(n!)kk!] where n replicates each at k sites are rearranged.

(iii) Once the R values for the rearranged labels were computed the locus followed by the estimated values gives an authentic glimpse of how the sampling distribution would be. From the number of recomputed R values which are equal to or greater than the R value of the original sample, the null hypothesis can be rejected at a significance level of (t+1)/(T+1) where t is the number of simulated values greater than or equal to original R out of a total T simulations.

(iii) Multivariate Methods:

Most of the multivariate routines offered by PRIMER target ordination of samples based on more than one trait considered simultaneously. The famous classical multivariate methods like Cluster analysis, Principal Component Analysis, Principal Co-ordinates analysis and Multidimensional Scaling are best utilized for such ordination of marine ecological data. For a focused elucidation let us focus on multi-dimensional scaling (MDS) as an ordination tool.

MDS is a complex numerical algorithm (can be conveniently left to suit the software's imagination!) but its base is logically very simple. The strength of this method is that it assumes very little model behaviour and the link between the final picture and that of the user's data is relatively easy to explain. By virtue of its being a basically non-parametric tool, it addresses the main criticisms hurled at Principal Components Analysis. The non-metric MDS, the purest non-parametric form that MDS can attain, starts with similarity or dissimilarity matrix among samples. This can be whatever similarity matrix that can be biologically relevant to the questions being asked of the data. In fact the superiority of this method lies in the fact that even with the similarity/dissimilarity matrices this method works on relative aspects of the pairings. MDS focuses on the rank of dissimilarity rather than the absolute measure of the same. In a nut shell MDS constructs a map of the samples in a specified number of dimensions, which attempt to satisfy all the conditions imposed by the rank similarity matrix. The two general features of MDS are

(1) The MDS plots can be arbitrarily scaled, located, rotated or inverted. Clearly the MDS does not deal with the absolute distance apart of two samples, instead relative distances have been focused.

(2) The algorithm of MDS methodology strives at reducing the distortion or stress when a multi dimensional similarity distance matrix is plotted in a reduced dimensionality meta plane. Not only the method reduces the stress but also gives a measure of the same.

A typical MDS algorithm would have the following stages:

a) The reduced number of dimensions have to be specified.

b) A starting mapping of the n samples have to be made , may by PCA or PCoA.

c) Regression of the interpoint distances in the new plot over the dissimilarity measure of the original setup. The regression may be plotted based on simple linear arrangement between the new measure d and the original multivariate dissimilarity a or the same may be based on a non-parametric paradigm.

d) The goodness of fit of the regression happens to be the stress defined using a statistic called stress which is the function involving squared differences between each unique pair distance and the regression based distance. If for all possible unique n(n-1)/2pairs the distances happen to be same then the stress is the least, viz 0.

e) The next step is to choose an optimization method which will alter the stress values for changes in ordination values of the plot and finally selecting a direction where the fall in stress values will be more significant than the rest.

f) And finally repeating steps from (c) to (e) till convergence is achieved.

Though loaded with a score of pluses MDS also has its share of drawbacks too. The main drawback is that this method is computationally more demanding and secondly convergence at a global minimum of stress is not always guatanteed.

Though PRIMER is replete with a bunch of such specif tools which are of immense utility value in Ecological and Marine research, we have considered an objectively selected few for getting an idea about the set of routines and how they tackle inferential issues. Hence it is advised that an exhaustive hands on experience with the various modules as well as study of select references will throw more light into using this software more efficiently along with interpreting the results in a more effective manner.

The following routines enshrined in the software are quite useful in numerically testing and robustly inferring and graphically assimilating large sets of community sample sets.

(i) CLUSTER (grouping) (ii) MDS (Ordination) (iii) PCA (recast visualisation) (iv) ANOSIM (hypothesis testing) (v) SIMPER (sample discrimination) (vi) BEST (trend correlations) (vii) BIOENV (paired group comparison) and (viii) PERMANOVA (permutational multivariate analysis of variance) among others. PRIMER also has extensive routines for estimating various beta, alpha and gamma diversity measuring indices. All these routines are built on a near total non-parametric platform thereby warding off the presumption and assumption blues. A classic routine worth focusing on is ANOSIM. Smartly worded to sound akin ANOVA this routine has a refreshingly different set of approach rooted deeply on all generated by the data alone. Under this procedure the samples are treated as arrays whose rows are samples and columns are the component resources like planktons etc. Based on the intensity of the resources available in each location, a rank-based similarity matrix is generated equivalent to the sample dimension. This index popularly known as Bray- Curtis similarity is then subjected to the inter and intra factor comparison yielding a functional known as R statistic. The value falling between 0 to 1 with lower limit indicating perfect similarity in divergence within factor groups and between them and the upper limit indicating near perfect similarity between pairs within groups as compared to those between them, thereby indicating significant inter group heterogeneity. The measure of the R value's robustness is also arrived at by estimating the R estimate on prior number of large recombinations of the sample data and noting down the values of R falling above the one realized from the original sample. Thus the non-parametric conceptualization right from estimating the group similarity to studying its distributional aspect is complete in this approach.

CRAN- R language's Vegan:

Vegan- A contributed package totally dedicated to the procedures and methods discussed by Clarke and Warwick (2001), whose software version is Primer-E. This contains most of the common tools like dissimilarity measures, Anosim, BioEnv etc.

Other modeling options with ecological data sets

To start with even the simple multiple regression itself is a model in the strict statistical sense which depicts the role and measure of causal factor upon explaining the variability of the response variables. These regression models fall under the category of linear models with normality assumptions. However with the responses being binary at times and highly skewed and noisy counts on the other end of the spectrum, the classical assumptions of normality which validates the tests of significance are most inapplicable in these datasets. Hence the more liberated and broader versions of the linear model called Generalised Additive Models (GAM) are the most aptly poised set of paradigms to fit into such situations. With a wide range of link functions, smooth functions and a range of distributions including non Gaussian like Poisson etc. GAMs can practically link any type of causative variable with any type of response sets which can be foreseen in ecological studies. With many measures for their rates of success based on Information criterion, the best of such group of models can always be zeroed in on.

The developments made in the time series modeling area including the methods to split the time spanned datasets into components of trend, cyclicity etc. have come in handy while dealing with the biotic and temporal factors and their influence on the community structures. The direction oriented process based decomposition of time series like Asymmetric Eigenvector Mapping and the direction free mapping like Morgan/s Eigenvector Mapping have given a specific thrust towards modeling the data with a view to focus on temporal and spatial angles.

Tools like Local contributions to beta diversity (LCBD) help in arriving at comparative measures of ecological uniqueness of samples which would go a long way in studying and inferring about the community structures.

To conclude, it can be safely assumed that the rate of development of computational statistics has lead a sort of newer opportunities and horizons in locating and studying the hitherto unknown camouflaged patterns and undercurrents existing in community structure datasets. With the rate of innovation higher on the computational front the treading of hitherto unheralded territory is becoming all the more in vogue thing for researchers.

Referres

Legendre P, Gauthier O. 2014 Statistical methods for temporal and space–time analysis of community composition data. Proc. R. Soc. B .

Clarke, KR, Warwick RM (2001). Change in marine communities: an approach to statistical analysis and interpretation, 2nd edition. **PRIMER**-E.

Other classical statistical text books.

CHAPTER

26

An Introduction to R Programming

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Introduction

R language is the GNU arm of S language, which has taken the computational world by storm in the last decade. Starting as a compendium of statistical tools, this language has grown up into a canopy lording over a research analysis environment thereby subsuming many hitherto complicated manoeuvres onto the realms of syntactical simplicity. As this an exponentially expanding field of development with ever exploding information downpour, it would be a near impossible task to frame it onto a short simple foundational discourse. However in the subsequent sections we would try to view the potential and the extent of practicality we would unravel the hidden features of the software through a GUI envelop also apart from the regular console and syntax based one. To get its power more understandable we would visualize its forays into the field of analytics using medium scale examples from marine fisheries data.

- R is "GNU S" — A language and environment for data manipulation, calculation and graphical display.
  - R is similar to the award-winning S system, which was developed at Bell Laboratories by John Chambers *et al.*,
  - a suite of operators for calculations on arrays, in particular matrices,
  - a large, coherent, integrated collection of intermediate tools for interactive data analysis,
  - graphical facilities for data analysis and display either directly at the computer or on hardcopy
  - a well developed programming language which includes conditionals, loops, user defined recursive functions and input and output facilities.
- The core of R is an interpreted computer language.
  - It allows branching and looping as well as modular programming using functions.
  - Most of the user-visible functions in R are written in R, calling upon a smaller set of internal primitives.

It is possible for the user to interface to procedures written in C, C++ or FORTRAN languages for efficiency, and also to write additional primitives.

R, S and S-plus- a brief time line

- S: an interactive environment for data analysis developed at Bell Laboratories since 1976
  - 1988 - S2: RA Becker, JM Chambers, A Wilks
  - 1992 - S3: JM Chambers, TJ Hastie
  - 1998 - S4: JM Chambers
- Exclusively licensed by *AT&T/Lucent* to *Insightful Corporation*, Seattle WA. Product name: "S-plus".
- Implementation languages C, Fortran.
- See: *http://cm.bell-labs.com/cm/ms/departments/sia/S/history.html*
- R: initially written by Ross Ihaka and Robert Gentleman at Dep. of Statistics of University of Auckland, New Zealand during 1990s.
- Since 1997: international "R-core" team of ca. 15 people with access to common CVS archive.

What R does and does not

- data handling and storage: numeric, textualo matrix algebrao
- hash tables and regular expressions
- high-level data analytic and statistical functions
- classes (Object Oriented "OO")
- graphics
- programming language: loops, branching, subroutines

- is not a database, but connects to DBMSs
- has no graphical user interfaces, but connects to Java, TclTko
- language interpreter can be very slow, but allows to call own C/C++ code
- no spreadsheet view of data, but connects to Excel/MsOffice
- no professional / commercial support

R and statistics

- Packaging: a crucial infrastructure to efficiently produce, load and keep consistent software libraries from (many) different sources / authors, which are updated at a best possible refresh rate

- Statistics: most packages deal with statistics and data analysis and there are many conduit and value addition libraries which augment the statistical inference
- State of the art: many statistical researchers provide their methods as R packages

Statistical Analysis

Data Analysis and Presentation happen to be the core strength of R software environment and the ease with which this is performed makes the environment as the ultimate winner. Faster computational routines and amenability of access and modification to interim steps and results makes the programming environment a winner.

- The R distribution contains functionality for large number of statistical procedures.
  - linear and generalized linear models
  - nonlinear regression models
  - time series analysis
  - classical parametric and nonparametric tests
  - clustering
  - smoothing
- R also has a large set of functions which provide a flexible graphical environment for creating various kinds of data presentations.

References For R

- The basic reference is The New S Language: A Programming Environment for Data Analysis and Graphics by Richard A. Becker, John M. Chambers and Allan R. Wilks (the "Blue Book") .
- The new features of the 1991 release of S (S version 3) are covered in Statistical Models in S edited by John M. Chambers and Trevor J. Hastie (the "White Book").
- Classical and modern statistical techniques have been implemented.
  - Some of these are built into the base R environment.
  - Many are supplied as packages. There are about 8 packages supplied

with R (called "standard" packages) and many more are available through the cran family of Internet sites (via http://cran.r-project.org).

- All the R functions have been documented in the form of help pages in an "output independent" form which can be used to create versions for HTML, LATEX, text *etc*.

– The document "An Introduction to R" provides a more user-friendly starting point.

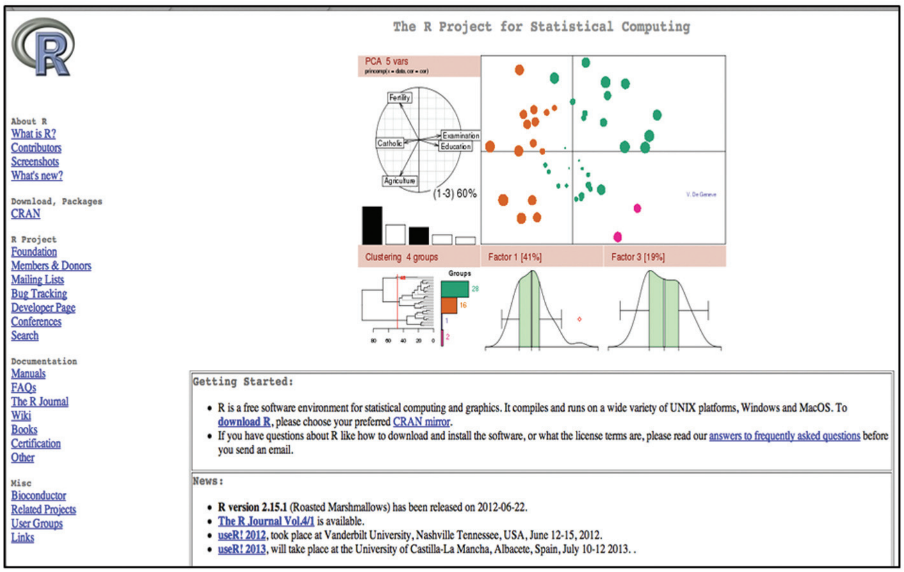
– An "R Language Definition" manual

– More specialized manuals on data import/export and extending R.

R installations

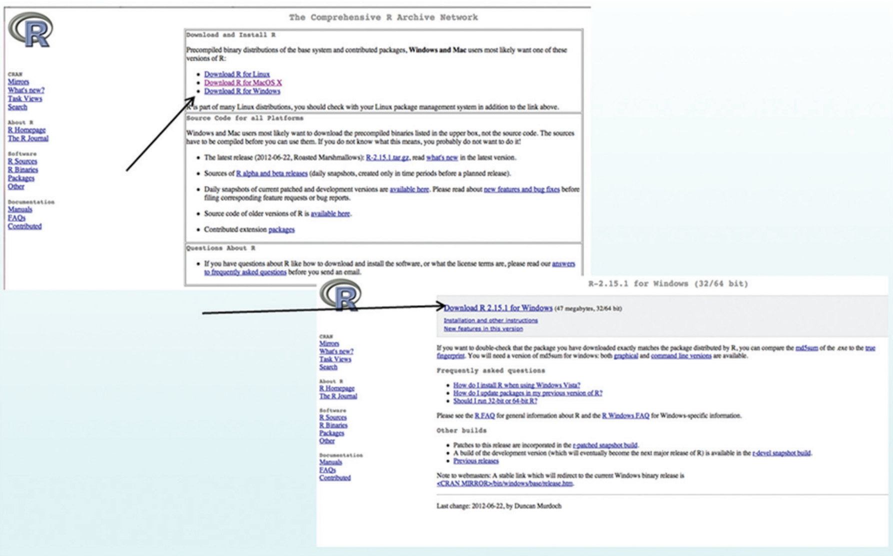
Getting Started

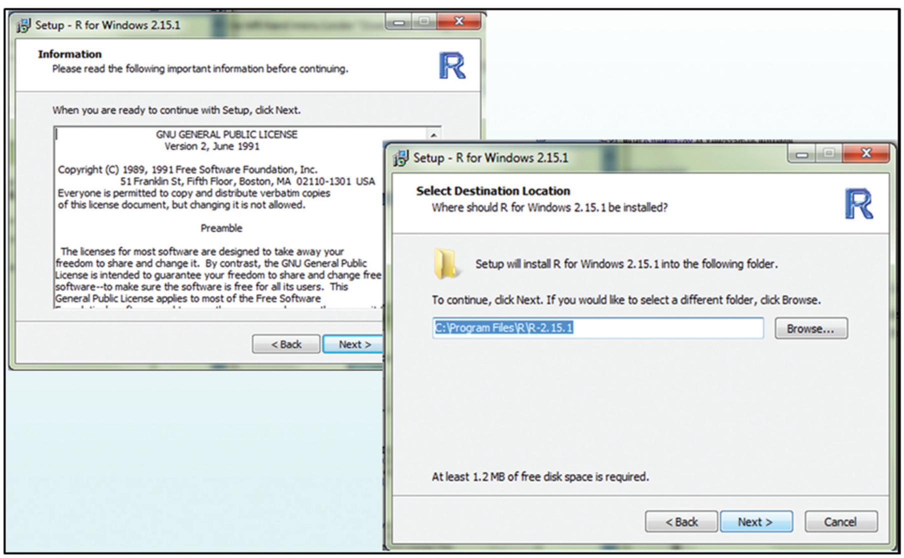
To install R on your MAC or PC the starting point has to be *http://www.r-project.org/*.



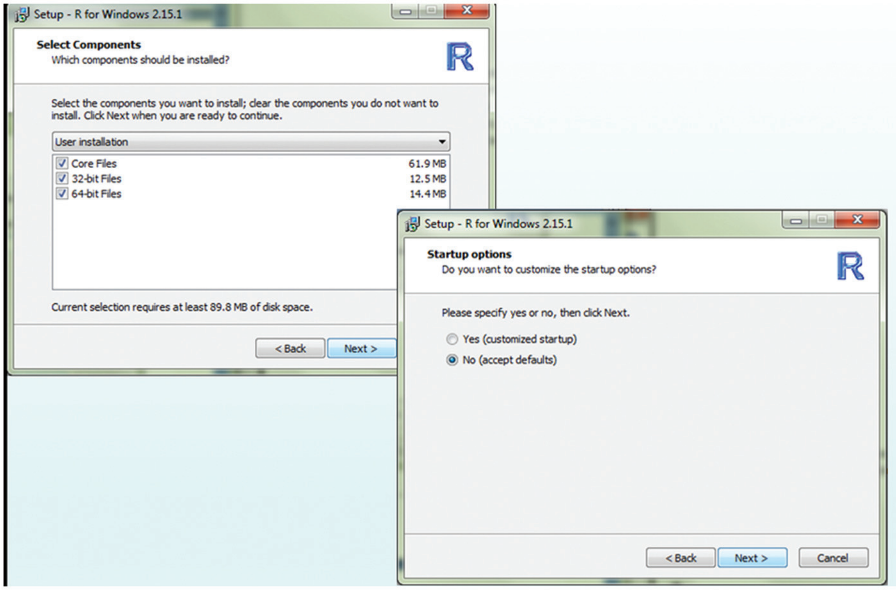
Depending on the choice of operating system the installer/ zip file with checksum may be downloaded and verified.

An effort to download R for Windows would have the following sequence of interactions with the portal, whose snapshots are given below:

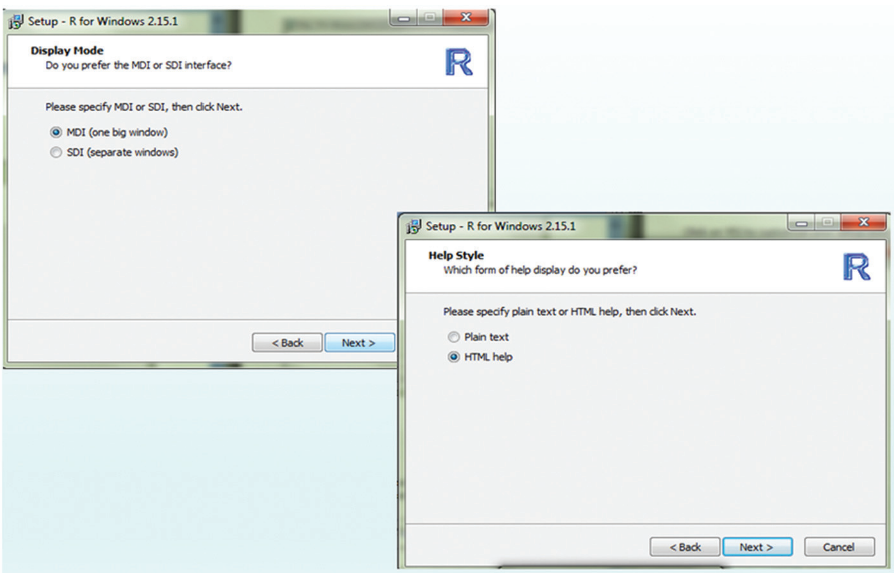




Its always a good idea to download all the files.



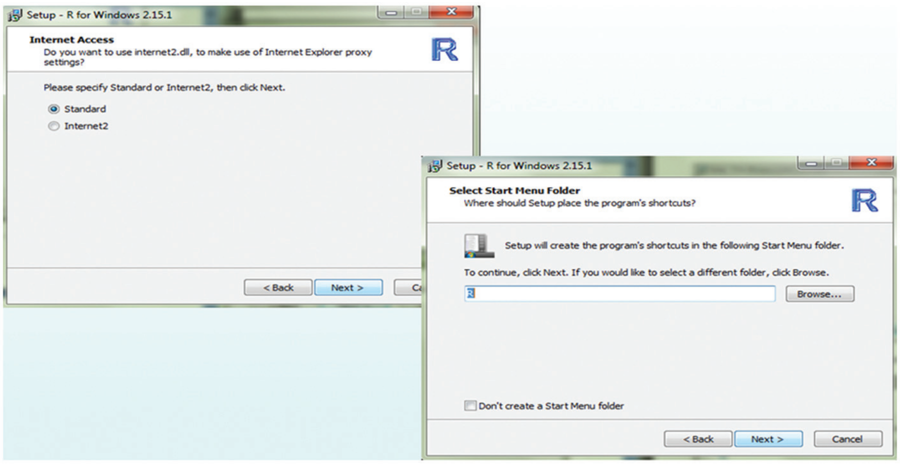
MDI is when the windows will be contained within one large window.

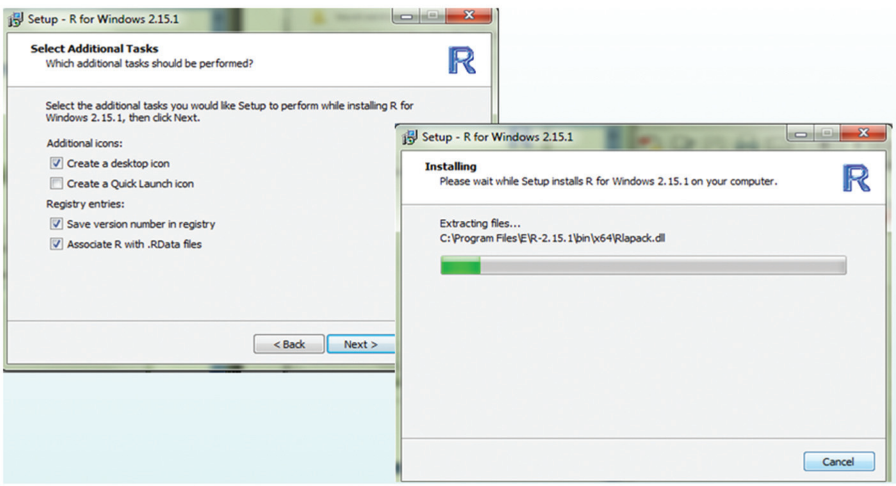


This is similar to how Excel is setup. SDI is a single document interface where every item will get its own window. This is similar to how SPSS is set up where it has separate data editor, viewer, and syntax windows. Once you choose which your prefer, click next.

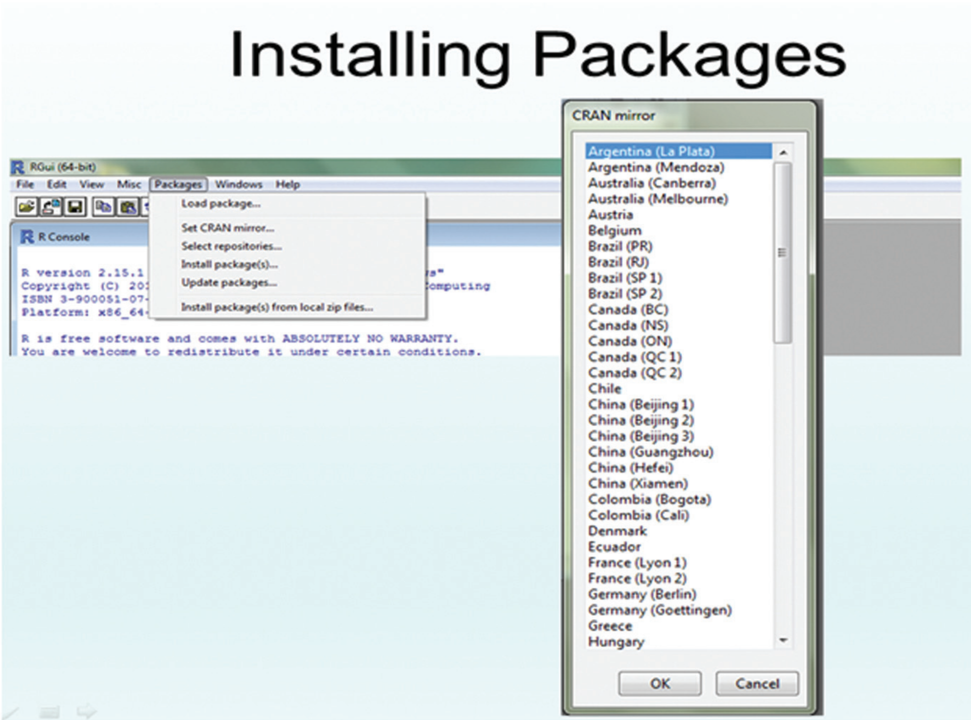
Choosing either html or plain text and clicking is the next step.

The installation may take awhile





To install packages on Windows, clicking on packages and install packages will be the next step.



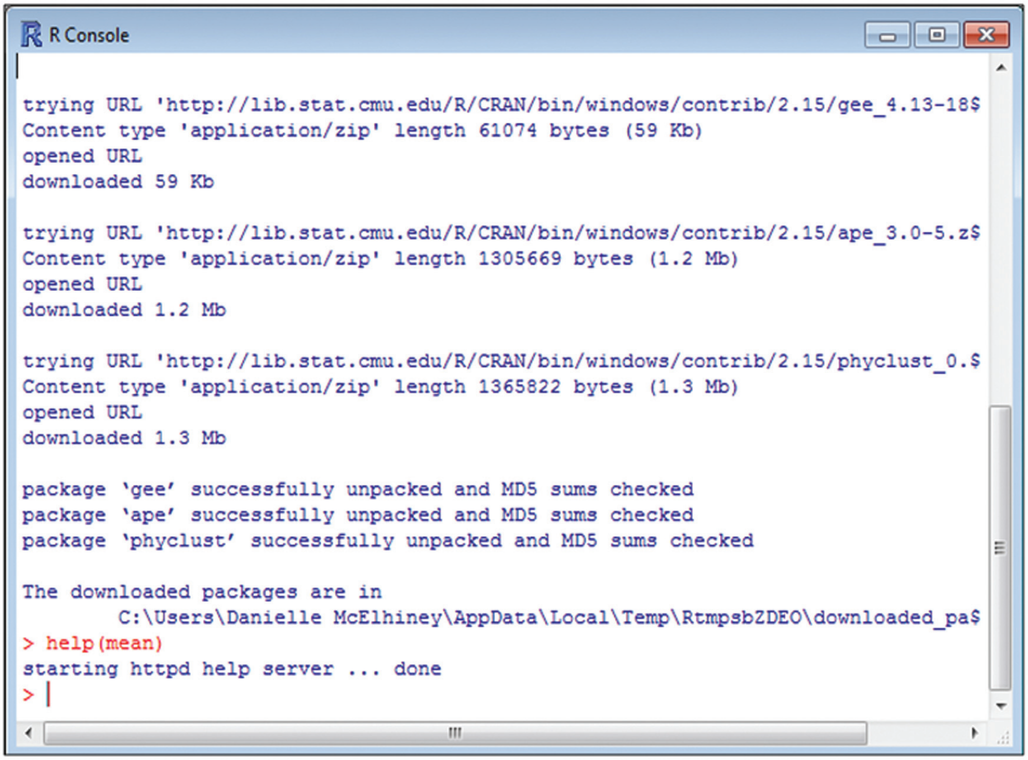
Scrolling down to country nearest and choosing a "mirror" that is close is the next step.

Scrolling down list until the requisite package is the next step, keeping in mind that R lists things in alphabetical order and by uppercase than lowercase. Once a package is clicked to load, R will install not only the package but all of the packages needed to run the package, including the dependencies.

To actually use the package, one has to go back to the package tab and click on load package.

Using Help Command

?solve translates on to giving details of help information about "solve" function whilst help.search or ?? allows searching for help in various ways.

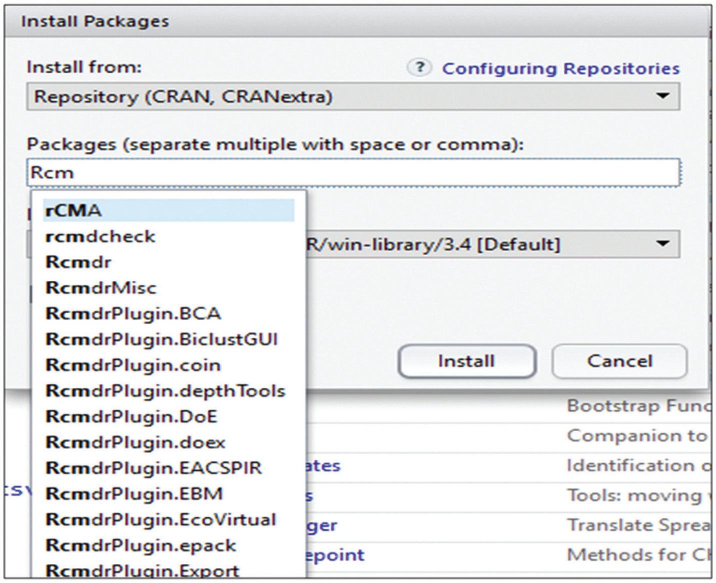


R Commander – A graphical interaction "skin" for R

R provides a powerful and comprehensive system for analysing data and when used in conjunction with the R-commander (a graphical user interface, commonly known as Rcmdr) it also provides one that is easy and intuitive to use. Basically, R provides the engine that carries out the analyses and Rcmdr provides a convenient way for users to input commands. The Rcmdr program enables analysts to access a selection of commonly-used R commands using a simple interface that should be familiar to most computer users. It also serves the important role of helping users to implement R commands and develop their knowledge and expertise in using the command line — an important skill for those wishing to exploit the full power of the program.(*http://www.rcommander.com/*)

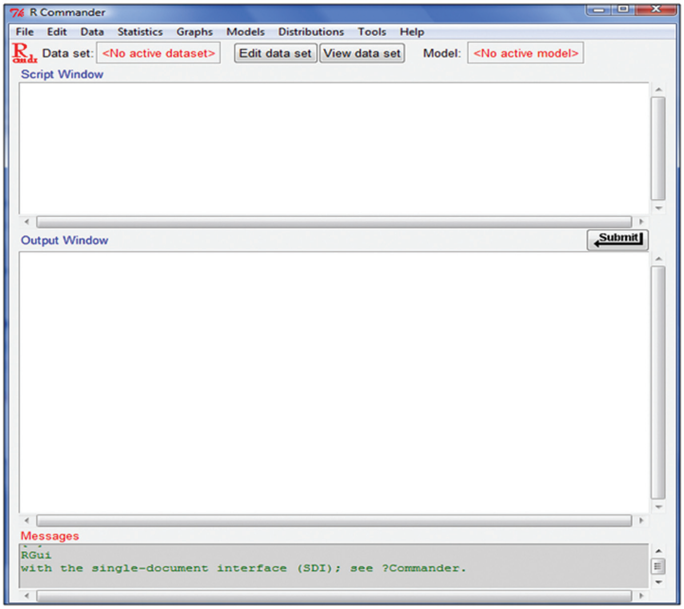
a) Loading R Commander

– Packages -> Install Packages -> Cran Mirror Selection -> Rcmdr



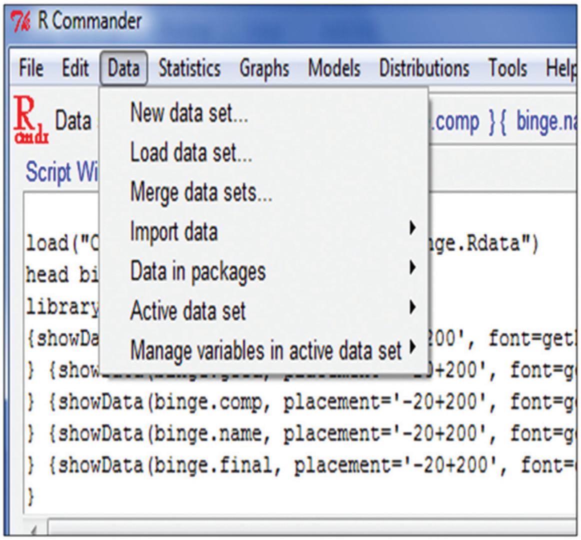
b) Opening R Commander

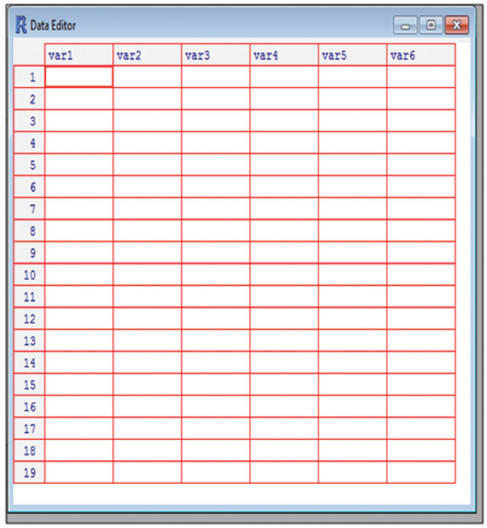
Open R -> Packages -> Load Packages -> Rcmdr



c) Loading Data

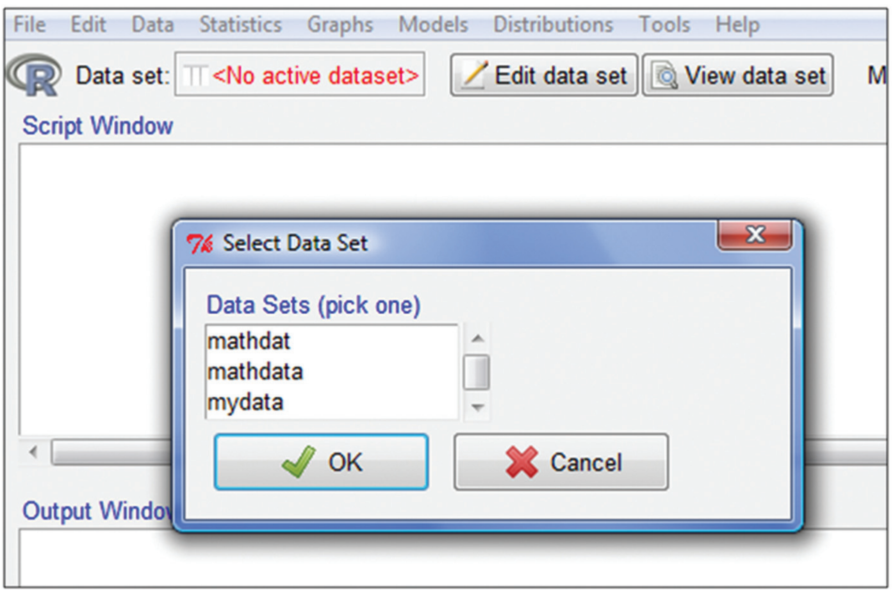
Data->Load data





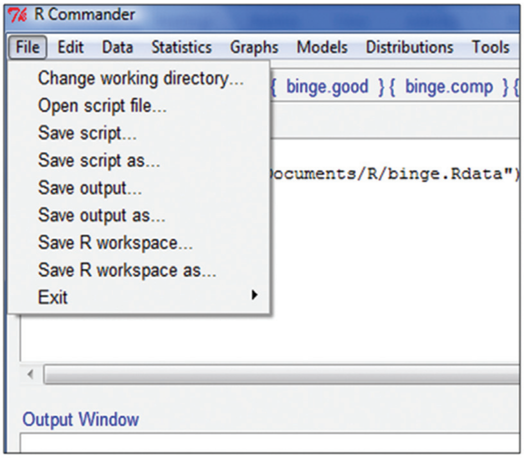
d) Active Data selection

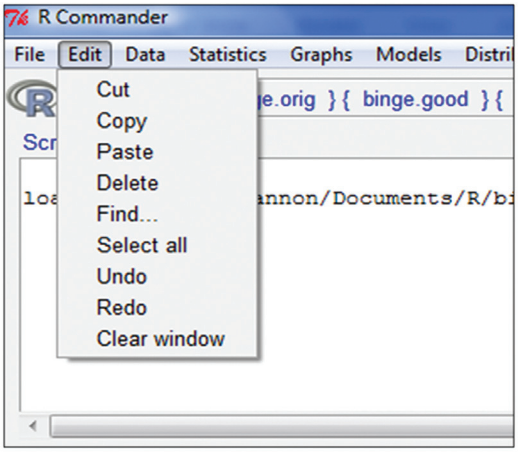
Data ->Active data set -> Select active data set



e) Menu driven File edit options

Script will save it as an R file .R and Output will save it as a text file. .txt

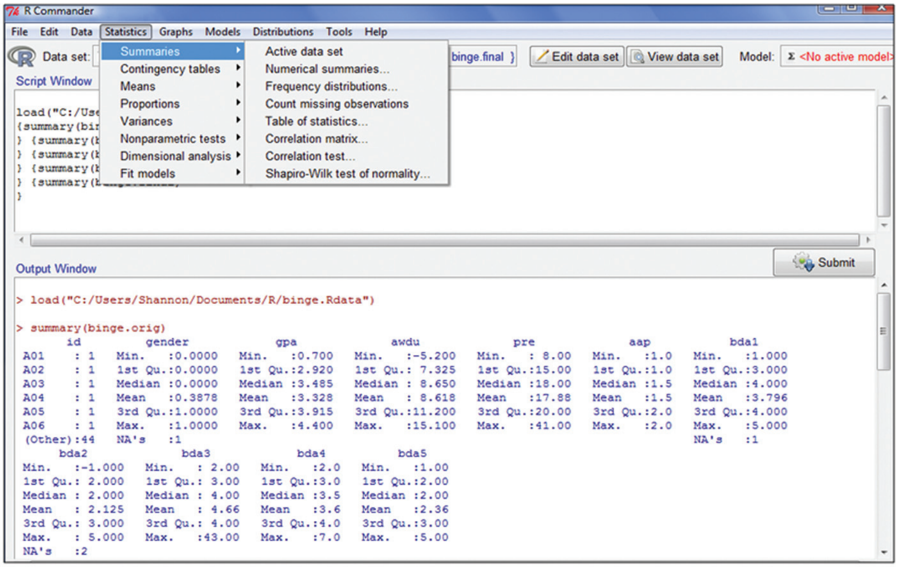




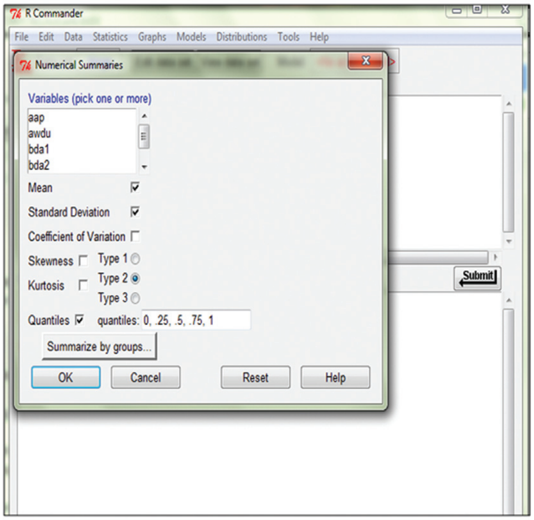
f) Summary of the data

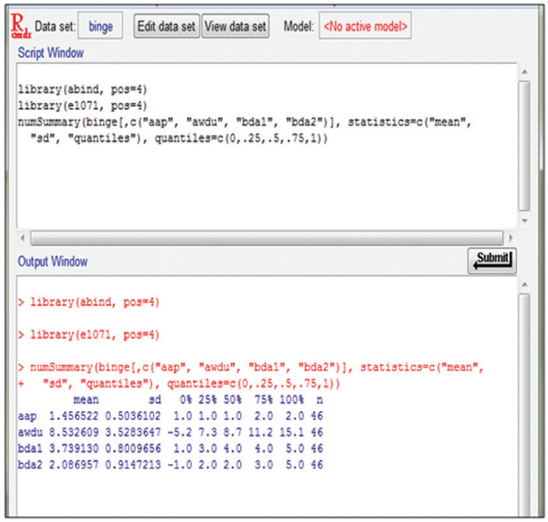
Statistics -> Summaries

Numerical Summeries – can also provide mean, standard deviation, skewness, kurtosis *etc.*

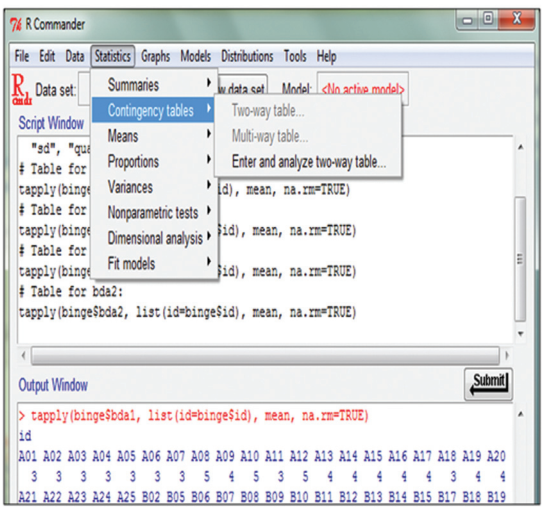


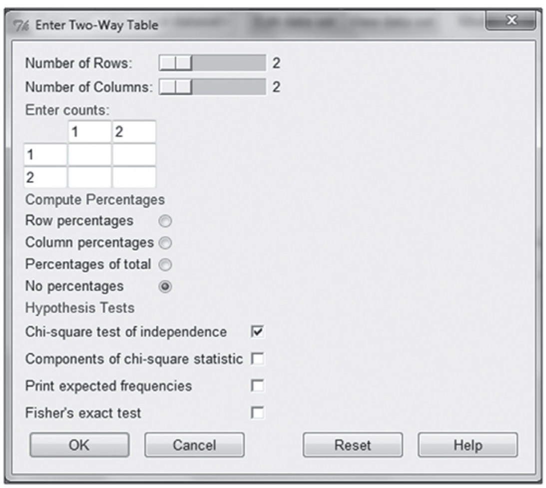
g) Mean, Standard Deviation, Skewness, Kurtosis





h) Contingency Tables

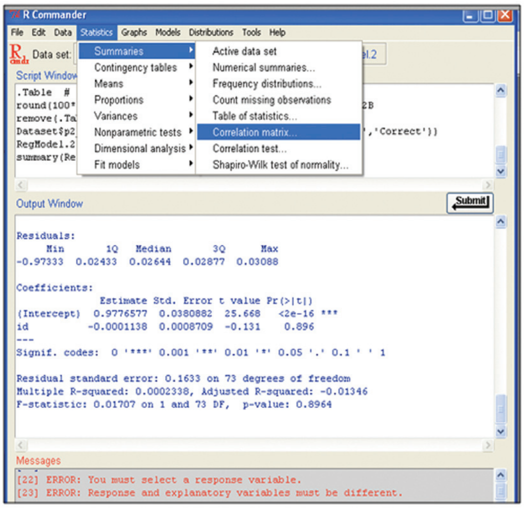


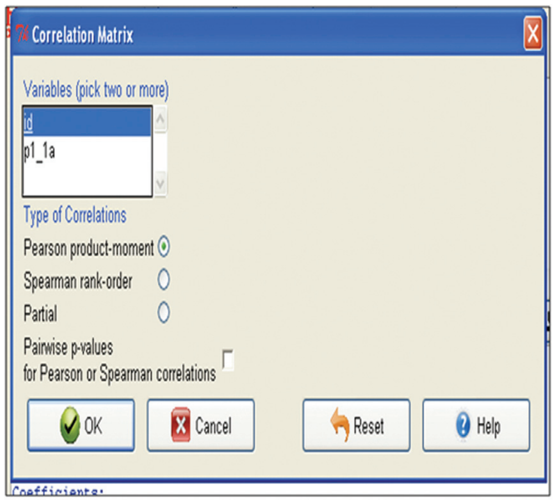


i) Correlations in R Commander

Correlation analysis can be done with R as follows.

Correlation is a bivariate analysis that measures the strengths of association between two variables and the direction of the relationship. In terms of the strength of relationship, the value of the correlation coefficient varies between +1 and -1. When the value of the correlation coefficient lies around ± 1, then it is said to be a perfect degree of association between the two variables. As the correlation coefficient value goes towards 0, the relationship between the two variables will be weaker. the direction of the relationship is simply the + (indicating a positive relationship between the variables) or - (indicating a negative relationship between the variables) sign of the correlation. Usually, in statistics, we measure four types of correlations: Pearson Correlation, Kendall rank correlation, Spearman correlation, and the Point-Biserial correlation. The software below allows you to very easily conduct a correlation.

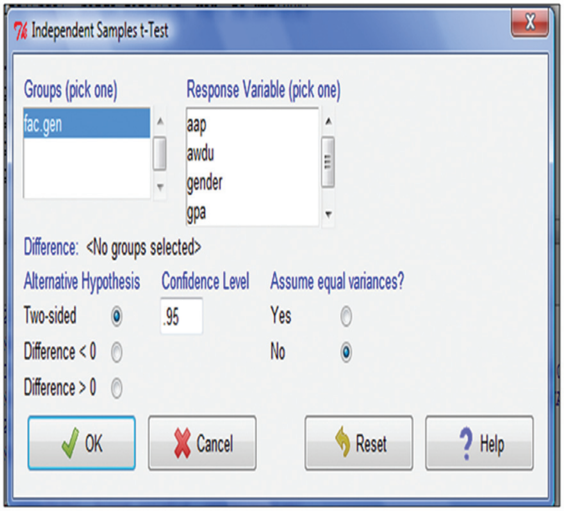


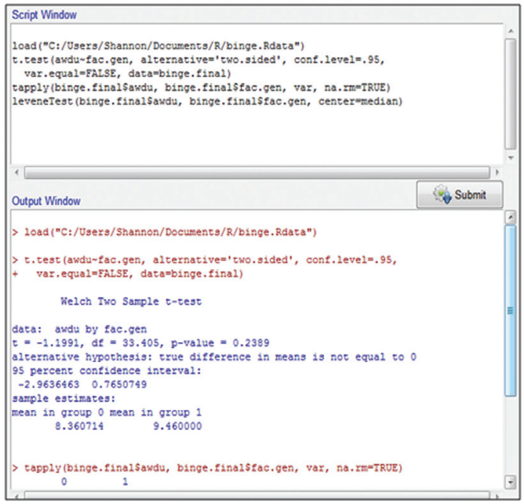


j) Independent T-Test

The independent t-test, also referred to as an independent-samples t-test, independent measures t-test or unpaired t-test, is used to determine whether the mean of a dependent variable (e.g., weight, anxiety level, salary, reaction time, *etc.*) is the same in two unrelated, independent groups (e.g., males vs females, employed vs unemployed, under 21 year olds vs those 21 years and older, *etc.*). Specifically, you use an independent t-test to determine whether the mean difference between two groups is statistically significantly different to zero.

Statistics->Independent T Test





k) One Way ANOVA

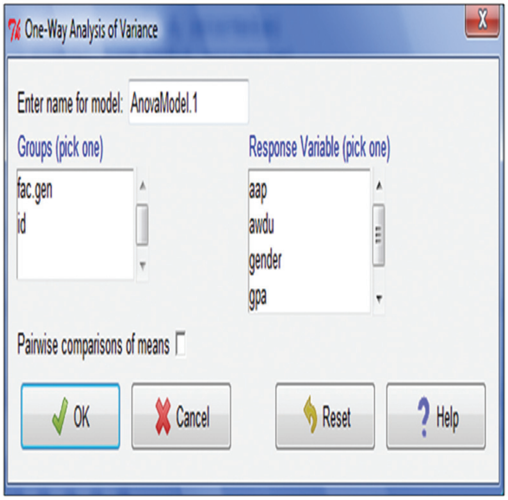
ANOVA(Analysis of Variance) is a statistical technique that assesses potential differences in a scale-level dependent variable by a nominal-level variable having 2 or more categories. For example, an ANOVA can examine potential differences in IQ scores by Country (US vs. Canada vs. Italy vs. Spain). The ANOVA, developed by Ronald Fisher in 1918, extends the *t* and the *z* test which have the problem of only allowing the nominal level variable to have just two categories. This test is also called the Fisher analysis of variance. ANOVAs are used in three ways: one –way Anova, two-way ANOVA, and N-way Multivariate ANOVA.

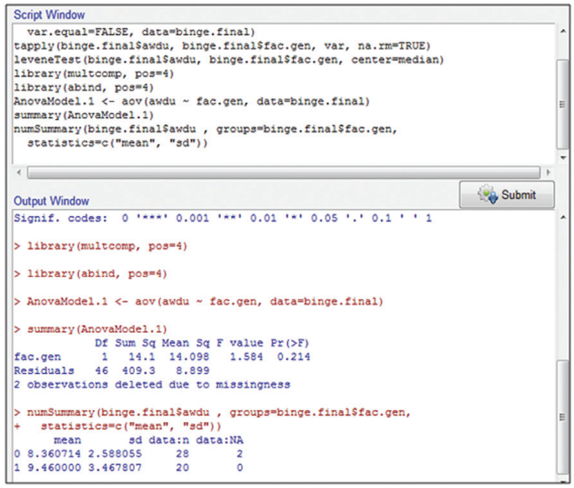
One-Way ANOVA

A one-way ANOVA refers to the number of independent variables—not the number of categories in each variables. A one-way ANOVA has just one independent variable. For example, difference in IQ can be assessed by Country, and County can have 2, 20, or more different Countries in that variable.

The software below allows you to easily conduct an ANOVA.

Statistics->One Way ANOVA





l) Factor Analysis

Factor analysis is a technique that is used to reduce a large number of variables into fewer numbers of factors. This technique extracts maximum common variance from all variables and puts them into a common score. As an index of all variables, we can use this score for further analysis. Factor analysis is part of general linear model(GLM) and this method also assumes several assumptions: there is linear relationship, there is no multicollinearity, it includes relevant variables into analysis, and there is true correlation between variables and factors. Several methods are available, but principal component analysis is used most commonly.

Types of factoring:

There are different types of methods used to extract the factor from the data set:

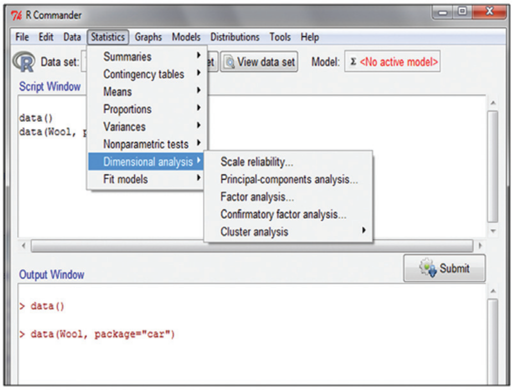
1. **Principal component analysis**: This is the most common method used by researchers. PCA starts extracting the maximum variance and puts them into the first factor. After that, it removes that variance explained by the first factors and then starts extracting maximum variance for the second factor. This process goes to the last factor.

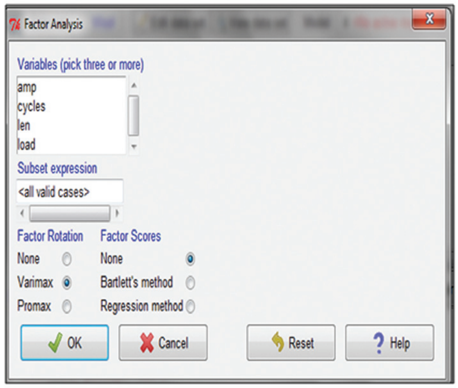
2. **Common factor analysis:** The second most preferred method by researchers, it extracts the common variance and puts them into factors. This method does not include the unique variance of all variables. This method is used in SEM.

3. **Image factoring:** This method is based on correlation matrix. OLS Regression method is used to predict the factor in image factoring.

4. **Maximum likelihood method:** This method also works on correlation metrix but it uses maximum likelihood method to factor.

5. **Other methods of factor analysis:** Alfa factoring outweighs least squares. Weight square is another regression based method which is used for factoring.





Result are shown as follows

Script Window

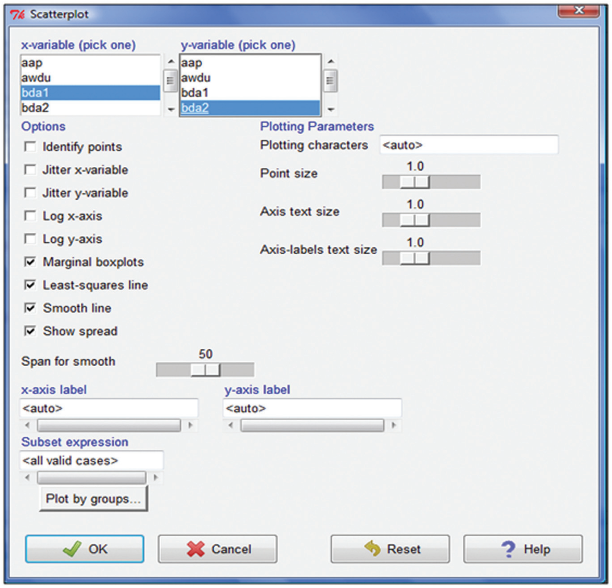
```
.FA <- factanal(~aap+awdu+bda1, factors=1, rotation="varimax",
  scores="none", data=binge.orig)
.FA
remove(.FA)
library(sem, pos=4)
```

```
> .FA <- factanal(~aap+awdu+bda1, factors=1, rotation="varimax",
+   scores="none", data=binge.orig)

> .FA

Call:
factanal(x = ~aap + awdu + bda1, factors = 1, data = binge.orig,     scores = "none", rotation = "varimax")

Uniquenesses:
  aap  awdu  bda1
0.849 0.324 0.596

Loadings:
     Factor1
aap  0.388
awdu 0.822
bda1 0.636
```

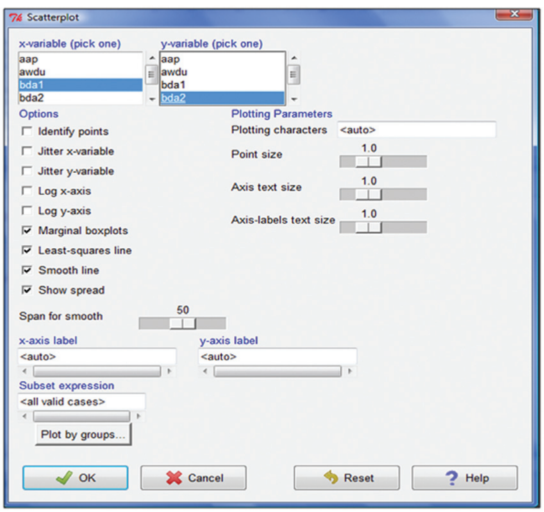
```
               Factor1
SS loadings      1.231
Proportion Var   0.410

The degrees of freedom for the model is 0 and the fit was 0

> remove(.FA)

> library(sem, pos=4)
```

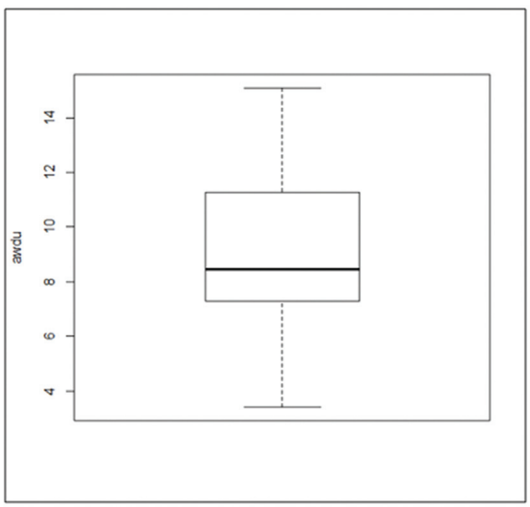
J) Graphs

Gparhs->Scatter plot



Gparhs->Box plot





R Basics

R is object base

Types of objects (scalar, vector, matrices and arrays Assignment of objects)

Building a data frame

Operation Symbols

Symbol	Meaning
+	Addition
-	Subtraction
*	Multiplication
/	Division
%%	**Modulo (estimates remainder in a division)**
^	Exponential

R as a Calculator

1550+2000

[1] 3550

or various calculations in the same row

2+3; 5*9; 6-6

[1] 5

[1] 45

[1] 0

As Mathematics

1+1

[1] 2

2+2*7

[1] 16

(2+2)*7

[1] 28

As Variables

x<-2

x

[1] 2

y<-3

y

[1] 3

5->z

(x*y)+z

[1] 11

Numbers in R: NAN and NA

NAN (not a number) NA (missing value) -Basic handling of missing values

Missing values are noise to statistical estimations. We are going to learn a basic command for handling missing values.

x<-**c**(1,2,3,4,5,6,NA)

mean(x)

[1] NA

mean(x,na.rm=TRUE)

[1] 3.5

Objects in R

Objects in R obtain values by assignment.

This is achieved by the gets arrow, <-, and not the equal sign, =.

Objects can be of different kinds.

Built in Functions

R has many built in functions that compute different statistical procedures.

Functions in R are followed by ( ). Inside the parenthesis we write the object (vector, matrix, array, dataframe) to which we want to apply the function.

Create a sequence of numbers from 32 to 44.

print(**seq**(32,44))

[1] 32 33 34 35 36 37 38 39 40 41 42 43 44

Find mean of numbers from 25 to 82.

print(**mean**(25:82))

[1] 53.5

Find sum of numbers frm 41 to 68.

```
print(sum(41:68))
## [1] 1526
```

Vectors

Vectors are variables with one or more values of the same type.

A variable with a single value is known as scalar. In R a scalar is a vector of length 1. There are at least three ways to create vectors in R: (a) sequence, (b) concatenation function, and (c) scan function.

Create two vectors of different lengths.

```
vector1 <- c(5,9,3)

vector2 <- c(10,11,12,13,14,15)

vector1

## [1] 5 9 3

vector2

## [1] 10 11 12 13 14 15
```

Arrays

Arrays are numeric objects with dimension attributes. The difference between a matrix and an array is that arrays have more than two dimensions.

```
# Take the above  vectors as input to the array.

result <- array(c(vector1,vector2),dim = c(3,3,2))

print(result)

## , , 1
##
##          [,1]   [,2]   [,3]
##   [1,]     5     10     13
##   [2,]     9     11     14
##   [3,]     3     12     15
##
```

```
## , , 2
##
##        [,1]  [,2]  [,3]
##  [1,]     5    10    13
##  [2,]     9    11    14
##  [3,]     3    12    15
```

Matrices

A matrix is a two dimensional array. The command colnames

Elements are arranged sequentially by row.

M <- **matrix**(**c**(3:14), nrow = 4, byrow = TRUE)

print(M)

```
##        [,1]  [,2]  [,3]
##  [1,]     3     4     5
##  [2,]     6     7     8
##  [3,]     9    10    11
##  [4,]    12    13    14
```

String Characters

In R, string variables are defined by double quotation marks.

letters<-**c**("a","b","c")

letters

[1] "a" "b" "c"

Subscripts and Indices

Select only one or some of the elements in a vector, a matrix or an array. We can do this by using subscripts in square brackets [ ].

In matrices or dataframes the first subscript refers to the row and the second to the column.

Dataframe

Researchers work mostly with dataframes. With previous knowledge you can built dataframes in R. Also, import dataframes into R.

```
# Create the data frame.
emp.data <- data.frame (
emp_id = c (1:5),
emp_name = c("Rick","Dan","Michelle","Ryan","Gary"),
salary = c(623.3,515.2,611.0,729.0,843.25),
 start_date = as.Date(c("2012-01-01", "2013-09-23", "2014-11-15", "2014-05-11",
"2015-03-27")),
stringsAsFactors = FALSE
)
# Print the data frame.
print(emp.data)
##   emp_id   emp_name   salary   start_date
## 1   1      Rick       623.30   2012-01-01
## 2   2      Dan        515.20   2013-09-23
## 3   3      Michelle   611.00   2014-11-15
## 4   4      Ryan       729.00   2014-05-11
## 5   5      Gary       843.25   2015-03-27
```

A journey wading through the amazing summarizing and analytical capabilities of R- a case study

Let the presumed data pertain to landings and standardized effort of a maritime state estimated by ICAR-CMFRI during the interregnum 1997 to 2013

calling file in R

```
klm<-read.csv("C:/Users/cmfri/Desktop/cpue_spcode_kldata.csv",header=TRUE)
```

To know header portion of the data set

```
head(klm)
##     year   month   species   raised     nomeff     stdcpue
## 1   1997   1       40        20595.35   122.0811   3.634042
## 2   1997   2       40        24201.10   114.3719   4.532246
## 3   1997   3       40        23497.64   255.0315   3.926130
```

```
## 4      1997     4      40      50176.75    154.7663     6.762821
## 5      1997     5      40      137626.24   314.6413     13.805531
## 6      1997     6      40      38149.38    649.1328     16.071358
```

To check the last few rows of the dataset

tail (klm)

```
##            year    month   species   raised    nomeff      stdcpue
## 245815     2013    7       4580      0         0.000000    0.000000
## 245816     2013    8       4580      1674      2.059835    1.667304
## 245817     2013    9       4580      0         0.000000    0.000000
## 245818     2013    10      4580      0         0.000000    0.000000
## 245819     2013    11      4580      0         0.000000    0.000000
## 245820     2013    12      4580      0         0.000000    0.000000
```

to know the observations in the data

length(klm)

```
## [1] 6
```

to know the structure of the dataframe

str(klm)

```
## 'data.frame':    245820 obs. of  6 variables:
##  $ year   : int  1997 1997 1997 1997 1997 1997 1997 1997 1997 1997 ...
##  $ month  : int  1 2 3 4 5 6 7 8 9 10 ...
##  $ species: int  40 40 40 40 40 40 40 40 40 40 ...
##  $ raised : num  20595 24201 23498 50177 137626 ...
##  $ nomeff : num  122 114 255 155 315 ...
##  $ stdcpue: num  3.63 4.53 3.93 6.76 13.81 ...
```

Descriptive statistics analysis

summary(klm)

```
##      year         month          species       raised
##  Min.   :1997   Min.   : 1.00   Min.   :   0   Min.   :     0
##  1st Qu.:2001   1st Qu.: 3.75   1st Qu.: 867   1st Qu.:  0
##  Median :2005   Median : 6.50   Median :1513   Median :  0
```

```
## Mean   :2005   Mean   : 6.50   Mean   :2201   Mean   :   42699
## 3rd Qu.:2009   3rd Qu.: 9.25   3rd Qu.:4016   3rd Qu.:       0
## Max.   :2013   Max.   :12.00   Max.   :9999   Max.   :71536031
##                                               NA's   :30
##     nomeff           stdcpue
## Min.   :     0.0   Min.   :   0.000
## 1st Qu.:     0.0   1st Qu.:   0.000
## Median :     0.0   Median :   0.000
## Mean   :   154.2   Mean   :   7.112
## 3rd Qu.:     0.0   3rd Qu.:   0.000
## Max.   :119100.1   Max.   :5600.000
##
```

If further enhanced list of summary statistics information about the data like third and fourth order moments, then the describe function of psych or summary function would come in handy.

```
library(psych)
describe(klm[,3:6])
##         vars      n     mean        sd median trimmed     mad min
## species    1 245820  2201.15   1951.83   1513 1941.16 1257.24   0
## raised     2 245790 42699.02 719150.48      0   62.52    0.00   0
## nomeff     3 245820   154.25   1543.66      0    0.16    0.00   0
## stdcpue    4 245820     7.11     52.38      0    0.11    0.00   0
##                max      range  skew kurtosis      se
## species     9999.0     9999.0  1.40     1.91    3.94
## raised  71536030.7 71536030.7 44.70  2681.18 1450.57
## nomeff    119100.1   119100.1 22.83   770.70    3.11
## stdcpue     5600.0     5600.0 21.65   971.06    0.11
```

If one wants to study monthly catch grouped information so that an idea about issues like which month (used as a group) would have etched up maximum landings/ catch, then simple literally rooted commands like describeBy (psych) or aggregate would come in handy.

```
library(psych)
describeBy(klm$raised,klm$month)
##
##  Descriptive statistics by group
## group: 1
##    vars     n     mean       sd median trimmed mad min      max    range
## X1    1 20485 41379.48 784622.6      0  146.65   0   0 51193526 51193526
##     skew kurtosis      se
## X1 46.55  2497.42 5482.05
## ------------------------------------------------------------------------
## group: 2
##    vars     n     mean       sd median trimmed mad min      max    range
## X1    1 20485 32904.06 535506.3      0  113.45   0   0 45468199 45468199
##     skew kurtosis      se
## X1 49.62  3259.68 3741.51
## ------------------------------------------------------------------------
## group: 3
##    vars     n     mean       sd median trimmed mad min      max    range
## X1    1 20485 39087.37 569052.1      0  162.51   0   0 31762665 31762665
##    skew kurtosis      se
## X1 38.4  1796.15 3975.89
## ------------------------------------------------------------------------
## group: 4
##    vars     n     mean     sd median trimmed mad min      max    range
## X1    1 20471 33795.18 477389      0   64.13   0   0 31931384 31931384
##     skew kurtosis      se
## X1 42.59  2353.01 3336.59
## ------------------------------------------------------------------------
```

```
## group: 5
##    vars     n     mean       sd median trimmed mad min      max    range
## X1    1 20485 37566.67 469275.5      0    96.2   0   0 30492626 30492626
##     skew kurtosis      se
## X1 33.18  1478.99 3278.76
## ------------------------------------------------------------------------
## group: 6
##    vars     n    mean       sd median trimmed mad min      max    range
## X1    1 20485 34552.2 655525.6      0   30.67   0   0 65432961 65432961
##     skew kurtosis      se
## X1 61.23  5239.89 4580.07
## ------------------------------------------------------------------------
## group: 7
##    vars     n    mean       sd median trimmed mad min      max    range
## X1    1 20485 32621.2 643003.1      0       0   0   0 49428947 49428947
##     skew kurtosis      se
## X1 42.19  2362.03 4492.57
## ------------------------------------------------------------------------
## group: 8
##    vars     n     mean       sd median trimmed mad min      max    range
## X1    1 20484 57397.86 713381.8      0   31.03   0   0 38795185 38795185
##     skew kurtosis      se
## X1 26.21   920.16 4984.42
## ------------------------------------------------------------------------
## group: 9
##    vars     n     mean       sd median trimmed mad min      max    range
## X1    1 20485 55833.65 901880.9      0    34.3   0   0 71536031 71536031
##     skew kurtosis      se
## X1 41.11  2415.63 6301.32
## ------------------------------------------------------------------------
```

```
## group: 10
##    vars     n     mean       sd median trimmed mad min      max    range
## X1    1 20484 57071.88 915432.9      0   89.05   0   0 55973676 55973676
##     skew kurtosis      se
## X1 34.05  1453.38 6396.16
## ------------------------------------------------------------
## group: 11
##    vars     n     mean     sd median trimmed mad min      max    range
## X1    1 20485 51210.52 915220      0  133.56   0   0 49127745 49127745
##     skew kurtosis      se
## X1 36.33  1488.92 6394.51
## ------------------------------------------------------------
## group: 12
##    vars     n     mean       sd median trimmed mad min      max    range
## X1    1 20471 38960.92 830555.4      0  134.37   0   0 66844967 66844967
##    skew kurtosis      se
## X1   56  3639.25 5804.96
```

Selecting subsets of data:

```
#to know the whole species entries
t<-klm$species
length(t)
## [1] 245820
# to know the june species entries
d<-klm$species[klm$month=="6"]
length(d)
## [1] 20485
```

to exclude some data

```
#exclude june catch and know the entries
e<-klm$species[klm$month!="6"]
```

length(e)

[1] 225335

correlation of the data

correlation between catch and effort for the whole period

attach(klm)

cor.test(raised,nomeff,method="pearson")

```
##
##  Pearson's product-moment correlation
##
## data:  raised and nomeff
## t = 434.94, df = 245790, p-value < 2.2e-16
## alternative hypothesis: true correlation is not equal to 0
## 95 percent confidence interval:
##  0.6572472 0.6617152
## sample estimates:
##      cor
## 0.659487
##multiple correlation
```

##Here we select the oilsardine catch.The oilsardine species code as 362

##we pick all the years monthly oil sardine

sp362<-klm[(klm$species=="362"),]

cordat<-sp362[,4:6]

cor(cordat)

```
 raised     nomeff    stdcpue
raised  1.0000000 0.45713639 0.61135090
nomeff  0.4571364 1.00000000 0.06860281
stdcpue 0.6113509 0.06860281 1.00000000
```

Linear regression & ANOVA

fit <- **lm**(raised~ year + month + nomeff, data=sp362)

show results

```
summary(fit)
##
## Call:
## lm(formula = raised ~ year + month + nomeff, data = sp362)
##
## Residuals:
##       Min        1Q    Median        3Q       Max
## -24406856  -5945766   -838374   4725596  40857882
##
## Coefficients:
## Estimate Std. Error t value Pr(>|t|)
## (Intercept) -2.148e+09  2.787e+08  -7.706 5.93e-13 ***
## year         1.072e+06  1.389e+05   7.716 5.59e-13 ***
## month        7.997e+05  1.969e+05   4.062 6.97e-05 ***
## nomeff       3.997e+02  4.493e+01   8.897 3.44e-16 ***
## —-
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 9689000 on 200 degrees of freedom
## Multiple R-squared:  0.4275, Adjusted R-squared:  0.4189
## F-statistic: 49.78 on 3 and 200 DF,  p-value: < 2.2e-16
# model coefficients
coefficients(fit)
##   (Intercept)          year         month        nomeff
## -2.147604e+09  1.072090e+06  7.997178e+05  3.997276e+02
# CIs for model parameters
confint(fit, level=0.95)
##                     2.5 %        97.5 %
## (Intercept) -2.697162e+09 -1.598046e+09
## year         7.980987e+05  1.346082e+06
## month        4.115344e+05  1.187901e+06
```

```
## nomeff      3.111348e+02  4.883205e+02
# predicted values
fitted(fit)
##         10609       10610       10611       10612       10613       10614
##   -3789651.96   -75345.54 15111313.36 13412874.31 17168949.26   120681.70
##         10615       10616       10617       10618       10619       10620
##   11475956.42  2176177.37  4491241.24 20281254.70 10248865.43  6278101.08
##         10621       10622       10623       10624       10625       10626
##    1848628.97  -945019.58 10648970.16 18599757.89  1915100.95  4945529.10
##         10627       10628       10629       10630       10631       10632
##    1844457.32  4524979.63  8480021.57 27270345.64 26410785.24  7449598.25
##         10633       10634       10635       10636       10637       10638
##    8195286.59 18056830.84 12504031.29  4797286.88   690139.61  7333241.94
##         10639       10640       10641       10642       10643       10644
##    9086615.20 12777192.22 16114211.77 21825496.12 23957847.88 30125417.82
##         10645       10646       10647       10648       10649       10650
##   16794955.21  8159428.15 18423291.70 38539644.49 22526843.37 15428828.71
##         10651       10652       10653       10654       10655       10656
##   19942372.43  8463199.11 16820433.97 16852255.88 19772511.73 16832240.83
##         10657       10658       10659       10660       10661       10662
##    6812947.52  2187489.33  3280344.12 24388104.43 18000977.41 15107404.98
##         10663       10664       10665       10666       10667       10668
##   11071325.90  8804492.99 11659447.99 15882452.30 13614255.15 14360781.30
##         10669       10670       10671       10672       10673       10674
##    4963345.25  3874425.71  8638896.83 15820079.63  9947652.94 10608928.30
##         10675       10676       10677       10678       10679       10680
##   11831223.68 10715678.08 18370843.69 18033007.59 24787443.71 20792659.27
##         10681       10682       10683       10684       10685       10686
##   10734553.89 14786524.50 23586068.72 15174415.81 14696669.45 21641645.35.88
##   26747332.20 27817053.16 27904369.27
# residuals
```

```
residuals(fit)
##       10609       10610       10611       10612       10613
##   5952459.84 12255563.09 -3371411.14 -4445741.27 -8889076.47
##       10614       10615       10616       10617       10618
##    986134.71 -5748266.48  -336390.21  2807133.26  1645172.74
##       10619       10620       10621       10622       10623
##  -3629105.70 -4577842.81  3072907.21  3243308.73 -5672890.07
##       10624       10625       10626       10627       10628
## -15696727.40   289232.12  2042122.32  1117366.99  2926082.40
##       10629       10630       10631       10632       10633
##   5230228.43 -20382271.56 -5264124.44 -5075967.51  1491577.71
##       10634       10635       10636       10637       10638
##  -9837151.49 -6712232.19  -764792.30  -437886.38  2231690.27
##       10639       10640       10641       10642       10643
##  -1443831.23 -2440345.04 14926587.99 -6794617.92  2635516.43
##       10644       10645       10646       10647       10648
## -17311907.92 -5709093.26  4952910.28 -6048902.56 -6642668.40
##       10649       10650       10651       10652       10653
##  -9406029.73 11491464.13 29486574.30  2963737.40  3482526.36
##       10654       10655       10656       10657       10658
##    764926.90  5721591.58 -8014761.85  -334238.52  5160023.79
##       10659       10660       10661       10662       10663
##   3802703.26 -10108379.25 -2107670.27 -3238790.51  6520269.00
##       10664       10665       10666       10667       10668
##   6117951.47  3707721.08  4118584.97   744008.66 -2535146.08
##       10669       10670       10671       10672       10673
##   5587891.61   247621.47 -2882708.00   800991.54  -911955.00
# anova table
anova(fit)
## Analysis of Variance Table
##
## Response: raised
```

```
##  Df  Sum SqMean Sq F valuePr(>F)
## year        1 4.6080e+15 4.6080e+15  49.083 3.663e-11 ***
## month       1 1.9813e+15 1.9813e+15  21.104 7.689e-06 ***
## nomeff      1 7.4316e+15 7.4316e+15  79.159 3.445e-16 ***
## Residuals 200 1.8776e+16 9.3882e+13
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
# covariance matrix for model parameters
```

vcov(fit)

```
##                    (Intercept)           year          month        nomeff
##     (Intercept)   7.767104e+16  -3.872335e+13  28849322448.9 -1.085409e+09
##            year  -3.872335e+13   1.930661e+10   -132736938.4  5.147853e+05
##           month   2.884932e+10  -1.327369e+08  38753042588.4 -5.204691e+05
##          nomeff  -1.085409e+09   5.147853e+05      -520469.1  2.018502e+03
# regression diagnostics
```

influence(fit)

```
## $hat
##       10609       10610       10611       10612       10613       10614
## 0.042348953 0.032174152 0.030947216 0.024014063 0.027363125 0.031587019
##       10615       10616       10617       10618       10619       10620
## 0.018101845 0.031744185 0.029944584 0.028749417 0.028915850 0.042004060
##       10621       10622       10623       10624       10625       10626
## 0.036951680 0.032836278 0.020628210 0.029105061 0.025090117 0.020127986
##       10627       10628       10629       10630       10631       10632
## 0.028928511 0.025311220 0.021317185 0.041136744 0.038894083 0.038442958
##       10633       10634       10635       10636       10637       10638
## 0.024751425 0.032951924 0.018613317 0.018864207 0.027982400 0.015391058
##       10639       10640       10641       10642       10643       10644
## 0.014401572 0.013346093 0.015061997 0.022355644 0.027879390 0.046154691
##       10645       10646       10647       10648       10649       10650
## 0.031627027 0.018558780 0.023833019 0.112821017 0.025427226 0.010871644
##       10651       10652       10653       10654       10655       10656
```

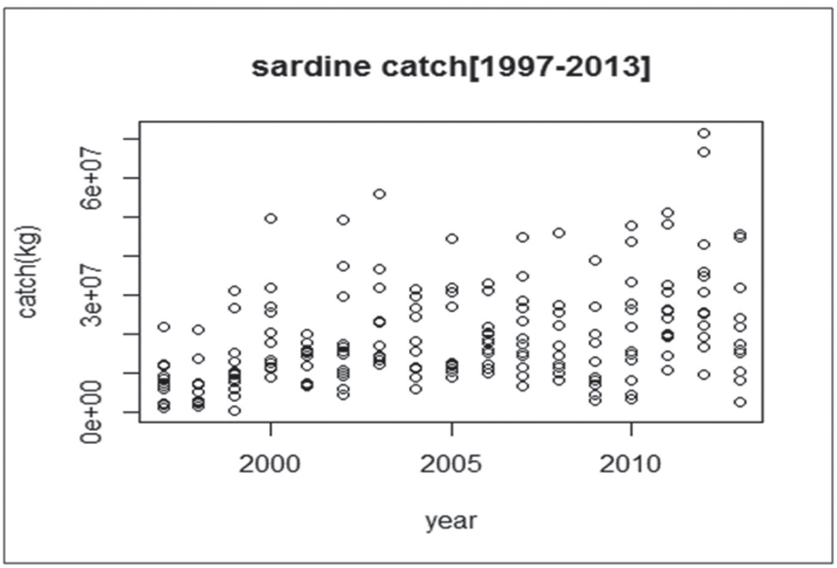
```
## 0.014936315 0.016434376 0.012730547 0.015052097 0.018993675 0.022811653
##       10657       10658       10659       10660       10661       10662
## 0.021590355 0.025598024 0.021891454 0.030677847 0.012303026 0.008431467
##       10663       10664       10665       10666       10667       10668
## 0.010270283 0.015731396 0.014200211 0.013621161 0.019758522 0.024082289
##       10669       10670       10671       10672       10673       10674
## $coefficients
##         (Intercept)          year         month       nomeff
## 10609  2.217824e+07 -1.095925e+04 -1.325088e+04 -3.148198546
## 10610  4.411931e+07 -2.183848e+04 -2.228032e+04 -4.498752468
## 10611 -1.067489e+07  5.318300e+03  5.379473e+03 -1.436946526
## 10612 -1.430707e+07  7.125744e+03  5.005198e+03 -1.244058740
## 10613 -2.792623e+07  1.393898e+046   .644383e+03 -3.898604484
## 10614  3.637567e+06 -1.803856e+03 -6.792737e+01 -0.548821439
## 10615 -1.912700e+07  9.531031e+03 -1.168978e+03 -0.136134257
## 10616 -1.236679e+06  6.142401e+02 -2.614444e+02  0.182574103
## 10617  1.017484e+07 -5.060185e+03  3.311361e+03 -1.300911103
## 10618  5.221933e+06 -2.616049e+03  2.285340e+03  0.594874799
## 10619 -1.269309e+07  6.332354e+03 -7.146199e+03  0.885644012
## 10620 -1.689093e+07  8.416379e+03 -1.142621e+04  2.385068449
## 10621  9.988869e+06 -4.931698e+03 -6.845283e+03 -1.449495213
## 10622  1.048887e+07 -5.182988e+03 -5.814728e+03 -1.523215775
## 10623 -1.631084e+07  8.103095e+03  8.519957e+03 -0.699865368
## 10624 -4.218674e+07  2.105372e+04  1.871018e+04 -8.082331986
## 10625  9.242638e+05 -4.579190e+02 -1.489350e+02 -0.132336511
## 10626  6.358893e+06 -3.155937e+03 -2.504379e+02 -0.691128004
## 10627  3.641035e+06 -1.805648e+03  3.989493e+02 -0.629386219
## 10628  9.337116e+06 -4.637748e+03  2.201757e+03 -1.355018464
## $sigma
##   10609   10610   10611   10612   10613   10614   10615   10616   10617
## 9704033 9673382 9710573 9708368 9692571 9713348 9704899 9713577 9711506
##   10618   10619   10620   10621   10622   10623   10624   10625   10626
```

```
##          9712887  9710099  9707947  9711071  9710794  9705104  9647742  9713585  9712507
##            10627    10628    10629    10630    10631    10632    10633    10634    10635
##          9713275  9711335  9706375  9600885  9706147  9706674  9713017  9687689  9701725
##            10636    10637    10638    10639    10640    10641    10642    10643    10644
##          9713453  9713556  9712299  9713060  9712046  9654918  9701385  9711759  9631991
##            10645    10646    10647    10648    10649    10650    10651    10652    10653
##          9704897  9707140  9703907  9700734  9690097  9679013  9482552  9711297  9710429
##            10654    10655    10656    10657    10658    10659    10660    10661    10662
##          9713454  9704972  9696589  9713578  9706537  9709783  9686303  9712444  9710871
##            10663    10664    10665    10666    10667    10668    10669    10670    10671
##          9702490  9703766  9710000  9709158  9713461  9711904  9705335  9713591  9711428
##            10672    10673    10674    10675    10676   106771     0678    10679    10680
##          9713440  9713390  9713495  9706020  9709067  9620081  9679152  9556146  9705788
##            10681    10682    10683    10684    10685    10686    10687    10688    10689
##          9703041  9712489  9696177  9713305  9713033  9713274  9711229  9713210  9707532
##            10690    10691    10692    10693    10694    10695    10696    10697    10698
##          9484558  9670016  9694154  9710393  9710677  9712970  9696964  9665645  9703363
##            10699    10700    10701    10702    10703    10704    10705    10706    10707
##          9699470  9711903  9695548  9685330  9698839  9696413  9712539  9713605  9645521
##            10708    10709    10710    10711    10712    10713    10714    10715    10716
##          9692194  9657695  9711752  9708527  9712793  9693026  9705844  9708928  9616936
##            10717    10718    10719    10720    10721    10722    10723    10724    10725
##          9700975  9709924  9687368  9702069  9706975  9713608  9712002  9705092  9711736
##
## $wt.res
##          10609         10610         10611         10612         10613
##     5952459.84   12255563.09   -3371411.14   -4445741.27   -8889076.47
##          10614         10615         10616         10617         10618
##      986134.71   -5748266.48    -336390.21    2807133.26    1645172.74
##          10619         10620         10621         10622         10623
##    -3629105.70   -4577842.81    3072907.21    3243308.73   -5672890.07
##          10624         10625         10626         10627         10628
```

```
## -15696727.40    289232.12   2042122.32   1117366.99   2926082.40
##        10629        10630        10631        10632        10633
##   5230228.43 -20382271.56  -5264124.44  -5075967.51   1491577.71
##        10634        10635        10636        10637        10638
##  -9837151.49  -6712232.19   -764792.30   -437886.38   2231690.27
##        10639        10640        10641        10642        10643
##  -1443831.23  -2440345.04  14926587.99  -6794617.92   2635516.43
##        10644        10645        10646        10647        10648
## -17311907.92  -5709093.26   4952910.28  -6048902.56  -6642668.40
```

Plots in R

```
##scatter plot
sp3621<-sp362[c(1:2,4)]
attach(sp3621)
## The following objects are masked from klm:
##
##     month, raised, year
plot(year,raised,main="sardine catch[1997-2013]",xlab="year",ylab="catch(kg))
```



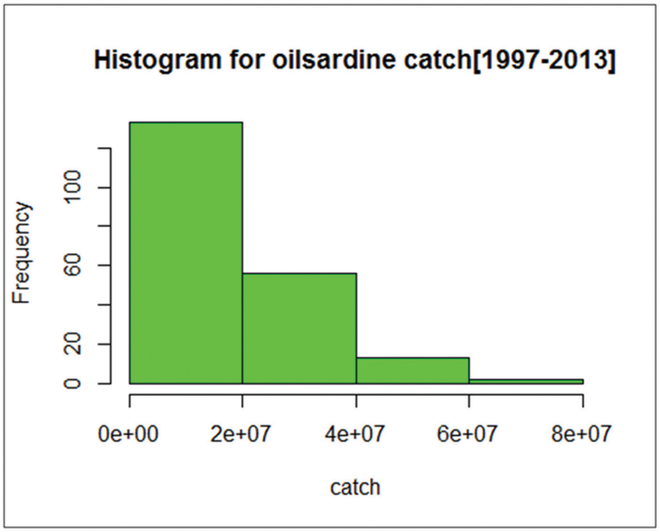
##Histogram

hist(raised,main="Histogram for oilsardine catch[1997-2013]",

lab="catch",

col="green",

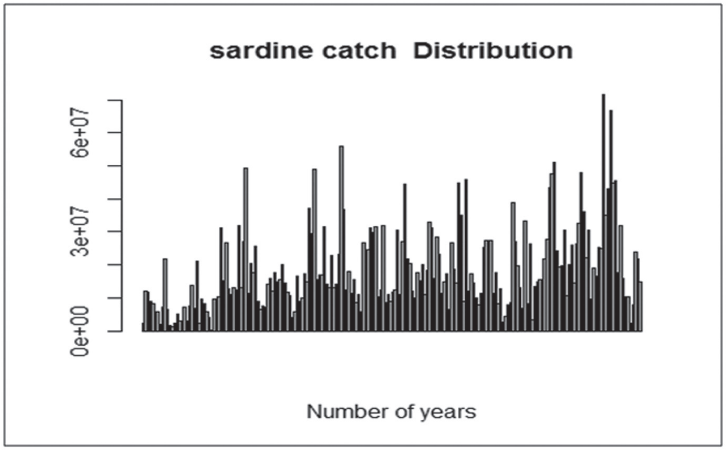
breaks=5)



##Bar plot

barplot(raised, main="sardine catch Distribution",

xlab="Number of years")

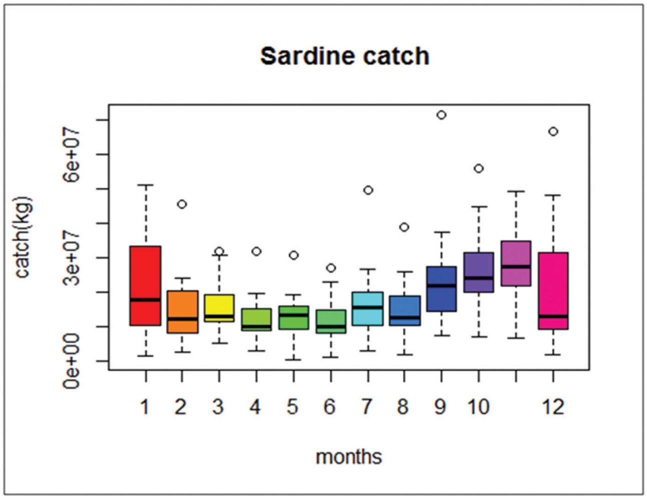


Boxplot in r

Boxplot of catch vs month

boxplot(raised~month,data=sp3621, main="Sardine catch ",

lab="months", ylab="catch(kg)",col=**rainbow**(**length**(**unique**(month))))



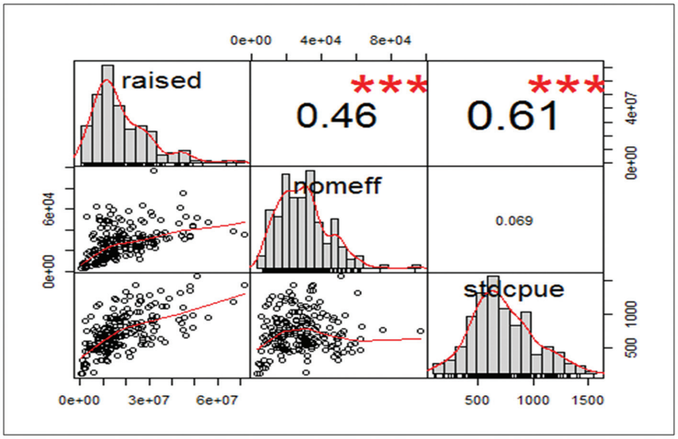
to plot a correlation in r

##we select sardine correlations

cordat<-sp362[,4:6]

library(PerformanceAnalytics)

chart.Correlation(cordat,method="pearson")



R for reading NetCDF data

NetCDF files contain one or more variables, which are usually structured as regular N-dimensional arrays. For example, you might have a variable named "Temperature" that is a function of longitude, latitude, and height. NetCDF files also contain dimensions, which describe the extent of the variables' arrays. In our Temperature example, the dimensions are "longitude", "latitude", and "height". Data can be read from or written to variables in arbitrary hyperslabs (for example, you can read or write all the Temperature values at a given height, or at a given latitude).

The R package 'ncdf4' allows reading from, writing to, and creation of netCDF files, either netCDF version 3 or (optionally) netCDF version 4. If you choose to create version 4 output files, be aware that older netcdf software might only be able to read version 3 files.

In fact this package can help extracting details from HDF5 format files too. This package can create NetCDF files from data.frames also. Nc_open() is the function to be used for opening a NetCDF fils and for creating a NetCDF file the function is nc_creat(). Once opened the attributes and variable names of the data can be got by using the generic print() command. To get specific variables the function is ncvar_get()

An example:

```
library(ncdf4)

ncold <- nc_open("states_population.nc")

data <- ncvar_get(ncold)

print("here is the data in the file:")

print(data)

nc_close( ncold )
```

The output is given below:

```
> ncold <- nc_open("states_population.nc")

> print(ncold)

File states_population.nc (NC_FORMAT_CLASSIC):

1 variables (excluding dimension variables):

int Pop[StateNo]

units: count

_FillValue: -1
```

```
long_name: Population
1 dimensions:
StateNo  Size:50
units: count
long_name: StateNo
1 global attributes:
 source: Census 2000 from census bureau web site
>
```

R in numerical methods

Taking cue from the fact that integration is infinitesimal addition, brutal algorithmic power of R has been put to use to find solutions of definite integrals. The most common function used for this purpose is integrate().

An example:

For the double integral given below

$$\int_0^1 \int_x^1 x\sin(y^2)\,dy\,dx$$

A couple of lines as given below would do the job in R environment

```
integrate(function(x) {
sapply(x, function(x) {
integrate(function(y) x*sin(y^2),x,1)$value
})
},0,1)
```

The output is given below (with error measure)

```
> integrate(function(x) {
+  sapply(x, function(x) {
+  integrate(function(y) x*sin(y^2),x,1)$value
+     })
+ },0,1)
0.09105548 with absolute error < 1e-15
>
```

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CHAPTER 27

Jellyfishes-Diversity, Biology-Importance in Conservation

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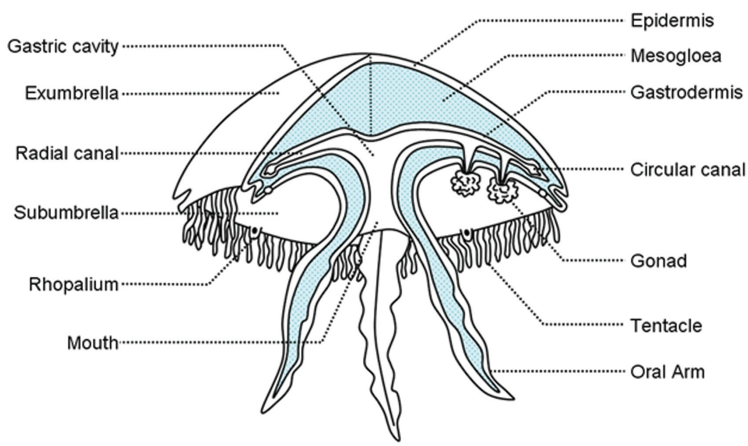
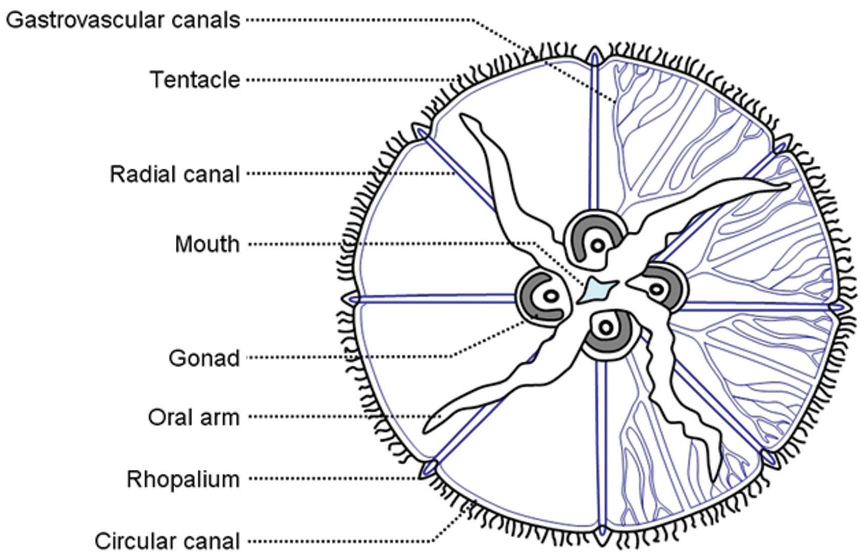
Jellyfish is a common word used for any gelatinous animal in marine waters. These include a wide variety of stinging and non-stinging jellyfishes. Jellyfishes are the oldest animal on planet earth from Pre-Cambrian period, and passed through 500 million years of natural selection. The term jellyfish generally refers to gelatinous zooplankton including medusae of the phylum Cnidaria(scyophomedusae, hydromedusae, cubomedusae and siphonohores) and planktonic members of the phylum Ctenophora, Salps and Pyrosomes etc. The true jelly fish are coming under the three Cinidarian classes *viz*., Hydrozoa, Scyphozoa and Cubozoa and seasonally swarm in the coastal waters. Among the three classes; representatives of Scyphozoan and Cubozoan are ranging in size from 2mm to 2 m bell diameter, however most of the hydrozoan jellyfishes are smaller than 2mm in bell diameter and belong to the mesoplankton. The biodiversity of the pelagic scyphozoan jellyfishes and Cubozoan jellyfishes is largely ignored in India other than a few works in this line. The first work on scyphozoan medusae was published way back in 1930, in which the scyphomedusae of Madras has been described with illustrations (Menon, 1930). Subsequent to this publication the above author has brought out scyphomedusae of Kurusadai Island (Menon, 1936). These are the two classic works which describe about the taxonomic features and distribution of scyphomedusae along the south east coast of India. Since then there is a long gap in the study of scyphomedusae in India. The scyphomedusae available in India was listed as 34 by Chakrapany (1984). The Medusae of the Travancore waters was studied by Nair (1951) and assessed the impact on fisheries.

Morphometric features of Jellyfishes

Jellyfishes are simple organisms with three layers of tissue viz., Endoderm, Ectoderm and Mesoderm. The body is composed of water over 90 percent. The umbrella shaped body which is called bell and the underside is covered with oral arms or tentacles. In jellyfishes difference in the bell margin is used as a differentiating character between different groups. The members of the order Semaeostomeae have



Aurelia medusa – cutaway diagram

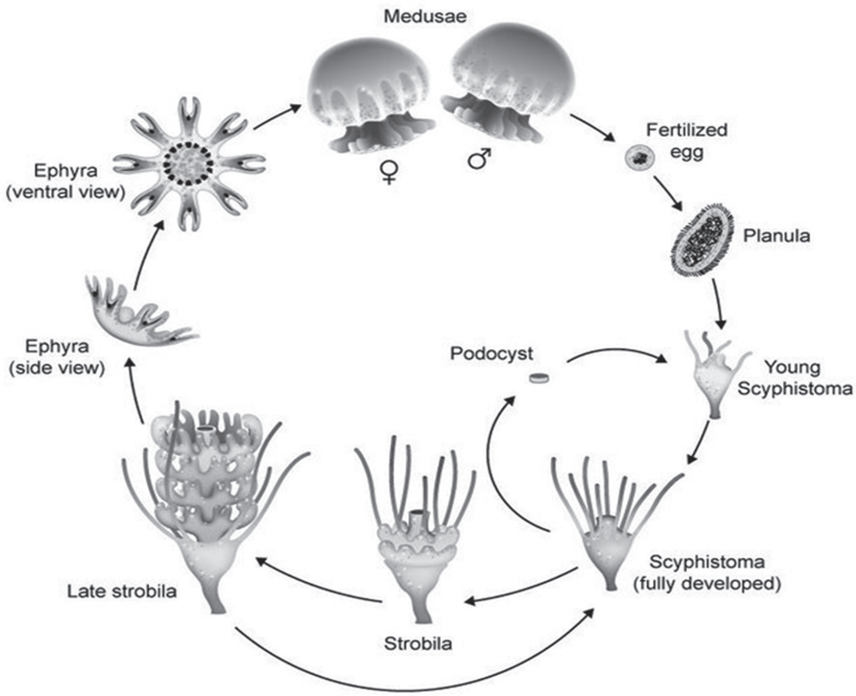


Aurelia medusa – subumbrella view

tentacles on the bell margin whereas the order Rhizostomeae have tentacles on the tip of oral arms. Jellyfish are 97% water and are semi-transparent.

Jellyfishes have two body layers, the outer layer epidermis and the inter layer gastrodermis. Between both layers is a thick layer of mesoglea which consists of fibres embedded in a hydrated matrix that contains cells. These layers of tissues make up the umbrella of the jellyfish which is usually bell shape, thus the umbrella is also known as the bell. The scyphozoan jellyfish are tetraradially symmetrical, meaning having many structures in multiples of four. It contains a simple gastrovascular cavity which acts as stomach. They are also characterized by having gastric filament in the stomach. Some scyphozoan jellyfish such as Semaestomeae contain an opening, or mouth at the subumbrella. There are four to eight oral arms near the mouth, which functions as arms to capture and transport food to the gastrovascular cavity. Jellyfish lack eyes, but possess many sensory receptors capable to detect light, pressure, temperature and gravity. These sensory receptors are concentrated in the marginal sense organ that contains the rhopalium (Nakanishi, 2015). Not all jellyfish possess tentacles. For Semaestomeae jellyfish, tentacles can be found at the margin of the bell or at the subumbrella whereas tentacles are absence from the Rhizostomeae jellyfish. Jellyfish contains network of canals that usually anestomoses with each others that formed various patterns.

Life cycle and biology: Cnidarian jellyfish, also called medusae, have complex life cycles that often involve a benthic stage: the polyp and the pelagic stage: the medusae or jellyfish. This bipartite life cycle alternates between an asexual, benthic polyp and a sexual, pelagic medusa. Medusae typically are produced asexually in abundance and grow rapidly in seasons (Russel, 1970).



Life cycle of the cannonball jellyfish *Stomolophus meleagris*; based on Calder (1982)

Diversity and distribution of jellyfishes in India:

Class Scyphozoa is ascribed with four orders, namely Stauromedusae, Coronatae, Semaeostomeae and Rhizostomeae with 65 genera and over 187 species globally. The diversity of scyphozoan jellyfishes along the Indian coastal waters has been reported as 29, however given the poor research attention given to this group, there may be more species to be recorded in the coming years.

Order Semaeostomeae:

The order Semaeostomeae composed of three families, four subfamilies, 18 genera and 56 species (Kramp, 1961). Semaestommeae jellyfish are characterized by four oral arms around the mouth. Tentacles are found at the umbrella margin. (Arai, 1997). The two important families of Semaeostomeae are Cyaneidae and Pelagiidae.

Order Rhizostomeae:

The order Rhizostomeae composed of two suborders, 10 families, 25 genera and approximately 89 species (Kramp, 1961). Rhizostomeae jellyfish are characterized by having bell margin cleft into lappet, with no tentacle on the bell margin, without a central mouth, with eight oral arms extended from the subumbrella, where each oral arms are bear numerous secondary mouths. Network of canals are found beyond the stomach. (Kramp, 1961; Arai, 1997). The important orders of this family are Mastigiidae, Versurigidae, Lychnorhizidea, Catostylidea, Lobonematidae and Rhizostomatida.

List of Scyphozoan jellyfishes Occuring in Indian waters

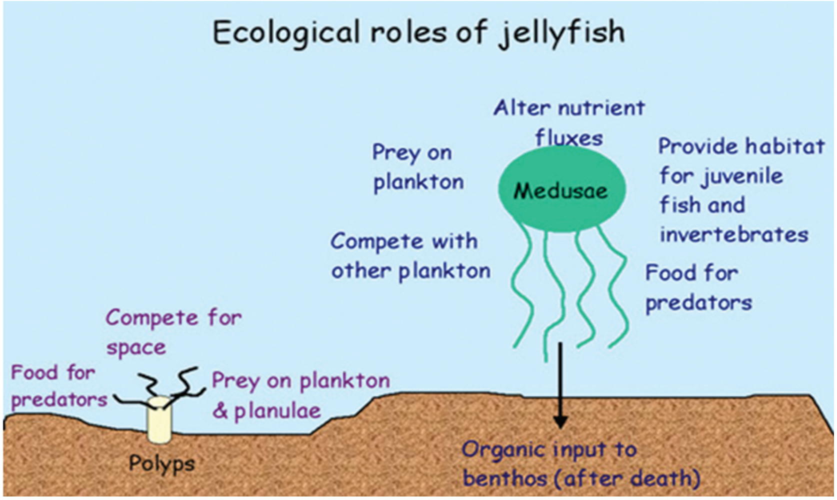
1 *Atolla wyvillei Haeckel, 1880*
2 *Nausithoe punctata Kölliker, 1853*
3 *Periphylla periphylla (Péron & Lesueur, 1810)*
4 *Cyanea nozakii Kishinouye, 1891*
5 *Chrysaora helvola Brandt, 1838*
6 *Chrysaora melanaster Brandt, 1838*
7 *Chrysaora quinquecirrha (Desor, 1848)*
8 *Pelagia noctiluca (Forsskål, 1775)*
9 *Aurelia aurita (Linnaeus, 1758)*
10 *Acromitus flagellatus (Haeckel)*
11 *Acromitus maculosus Light, 1914*
12 *Catostylus mosaicus (Quoy & Gaimard, 1824)*
13 *Crambionella stuhlmanni (Chun, 1896)*
14 *Crambionella orsini (Vanhöffen)*
15 *Lobonema smithii Mayer, 1910*
16 *Lobonemoides robustus Stiasny, 1920*
17 *Lobonemoides sewelli Rao, 1931*
18 *Lychnorhiza malayensis Stiasny, 1920*
19 *Rhopilema hispidum*
20 *Cassiopea andromeda (Forsskål, 1775)*
21 *Cephea cephea (Forskål, 1775)*
22 *Marivagia stellata Galil & Gershwin, 2010*
23 *Netrostoma coerulescens Maas, 1903*
24 *Netrostoma setouchianum (Kishinouye, 1902)*
25 *Mastigias papua (Lesson)*
26 *Versuriga anadyomene (Maas)*
27 *Phyllorhiza punctata Lendenfeld, 1884*
28 *Thysanostoma loriferum*
29 *Thysanostoma thysanura Haeckel, 1880*

List of Cubozoan Jellyfishes occurring in Indian waters

1. *Alatina alata (Reynaud, 1830)*
2. *Alatina madraspatana (Menon, 1930)*
3. *Tamoya gargantua Haeckel, 1880*
4. *Chiropsalmus quadrumanus (F. Muller, 1859)*
5. *Chiropsoides quadrigatus (Haeckel, 1880)*
6. *Chiropsoides buitendijki (van der Horst, 1907)*

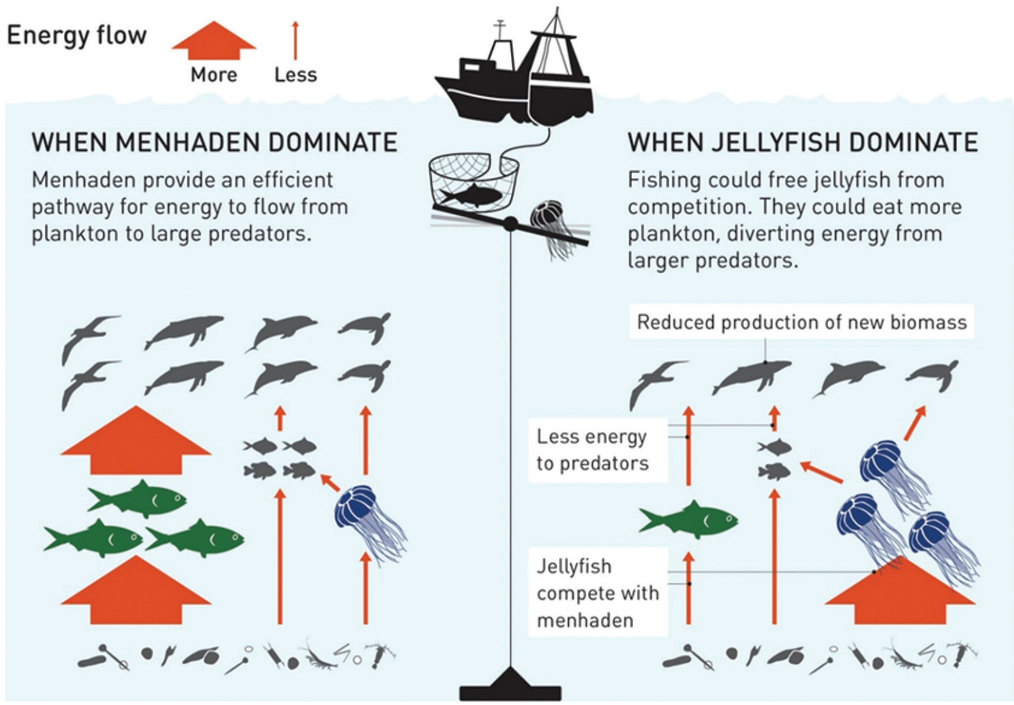
Ecosystem importance of Jellyfishes:

Jellyfishes are distributed globally and often forms swarms under favourable conditions that last for weeks to months before they collapse. Though jellyfish population swarms occur in many places at an increasing trend, but the lack of time series data on their distribution and abundance along the Indian coast prevent us from concluding their population dynamics. Establishing a time series data around the Indian subcontinent and island territories on the jellyfish abundance is difficult due the fact that in most case these jellatinous creatures get damaged in bottom trawls and zooplankton tows and not properly recorded. Jellyfish directly interfere with many human activities (reviewed by Purcell et al., 2007; Richardson et al., 2009), specifically, through stings (beach closures, tourism impacts, injuries, deaths), clogging intakes (coastal power and desalination plants, mining and military operations, shipping, aquaria), interference with fishing (clogged and split nets, spoiled catch, stung fishers, damaged gear, capsized boats), aquaculture (fish deaths, pens fouled by polyps), and marine biological surveys (interference with trawls and acoustic surveys). Jellyfish also have ecosystem impacts with indirect effects on fisheries resources that are difficult to quantify, such as their roles as predators of zooplankton, fish eggs and ichthyoplankton, as vectors for parasites, as food for fish, and as refugia and food for some species of juvenile fish.



Ecological roles of medusae and polyps. Adapted from Kingsford et al. 2000

Invasive species of jellyfish are reported in 21 of 45 LMEs. For the most part, invasive species were not responsible for the observed increases reflected in the results; however, the widespread detections demonstrate that jellyfish are truly global invaders of significant concern. Thriving populations of invasive jellyfish in systems like the Mediterranean and Black Seas should serve as warnings for other ecosystems around the globe, and it is likely that far more invasions have occurred than are reported (Holland et al., 2004). It is considered that the drivers of Change in jelly fish population, includes over-fishing, aquaculture, climate change, habitat modification, and introductions of alien species, suggest that human-caused coastal deterioration may have benefitted jellyfish and led to their increasing populations.



Potential ecosystem shift due to fishing- From fish dominated to jellyfish dominated(Robinson et al. 2015)

Potential ecosystem shift due to fishing- From fish dominated to jellyfish dominated(Robinson et al. 2015)

Gut content studies of Jellyfishes

In order to study the gut content of jellyfishes their gastric pouches are excised, opened and the contents rinsed through a 100-ìm mesh sieve. This is a common procedure for concentrating gut contents and handling samples of large medusae. The collection of jellyfish for gut content studies should be preferably done in night hours. All medusae should be studied within 35 min of collection, which is less than published prey digestion times (Arai 1997).

Global jellyfish Fisheries

Dried jellyfish is considered to be a delicacy in many Asian countries. Jellyfish are also purported to have beneficial medicinal properties and are traditionally used to treat ailments such as arthritis, hypertension and back pain (Hsieh et al. 2001). Jellyfish have been harvested off the coast of China for more than 1700 years (Omori & Nakano 2001)

Only jellyfish belonging to the Order Rhizostomeae are harvested for food. The rhizostomes are favoured because they are typically larger and have more rigid bodies than other scyphozoan orders. When processed, the rhizostomes produce a product that has the desirable, almost crunchy texture. Some species considered to be edible are:

Cepheidae	*Cephea cephea*
Catostylidae	*Catostylus mosaicus, Crambione mastigophora, Crambionella orsini*
Lobonematidae	*Lobonema smithi, Lobonemoides gracilis*
Rhizostomatidae	*Rhopilema esculentum, Rhopilema hispidum, Rhizostoma pulmo*
Stomolophidae	*Stomolophus meleagris, Stomolophus nomurai*

Indian Jellyfish fisheries

There is an active jellyfish fisheries along Kerala, Gujarat and Andhra Pradesh and four species support jellyfish fishery in India *viz*., *Crambionella stuhlmanni*, *C. orsini*, *Catostylus perezi*, *Rhopilema hispidum,* which are processed and exported to overseas markets.

Guidelines for Jellyfish studies

Preservation Method

Scyphozoans are typically preserved for morphological analyses in a solution of 4% formalin in seawater with the appropriate label (i.e. 4 parts formalin [37% w/v] and 96 parts seawater). Place the jellyfish in plastic container with a label (waterproof paper) and pour formalin until the organism is cover completely.

If you are using a plastic bag, place the organisms in a bag, fill it with formalin, twist the bag, and use a rubber band to wrap the plastic bag. When is tight enough, fold the tip of the plastic bag and with the last part of the rubber band secure the folded part of the bag. Excess 4% formalin solution is used, and it can be renewed after two weeks to ensure successful fixation.

Tissue storage for DNA studies

1. Flush the oral arms or bell margin with tapwater. Repeat several times to displace all debris.
2. Using clean forceps/scissors, cut a half-small-fingernail sized piece of tissue from the oral arm or bell margin.
3. Preserve the tissue in one vial of preservative. (Make sure there is excess preservative; guard against diluting the preservative with too much water).

4. With forceps hold a piece of oral arm and cut it with clean scissors or razor blades.
5. Place the piece of tissue in a vial with 95% ethanol

Specimen Information to be collected

Geographic location

Depth

Date (of collection)

Collector (e.g. your name)

Photograph

Whole jellyfish preserved? (yes/no; where)

Conditions

Photograph of the following features

Bell: Differences in the bell margin can be useful to distinguish orders of medusae.For example, the Semaeostomeae, in contrast to the Rhizostomeae, have tentacles on the bell margin.

Canal: Canal structure inside the bell

Cnidae: In Jelly fish, most cnidae are located in and around the tentacles and/or oral arms. Their shape is used in identification.

Mouth-arms: Differences in the form of the mouths distinguish orders of scyphomedusae. The Rhizostomeae have many small mouths distributed over their oral arms in contrast to semaeostomes, for example, which have a single, much larger, central mouth. The form and distribution of mouths over the oral arms can also be useful for distinguishing taxa within the Rhizostomeae.

Rhopalia: Rhopalia (singular rhopalium) are the most obvious sensory structures of scyphozoan jellyfish. They include specialized structures for sensing light (eyespots) and movement or direction with respect to gravity (statoliths).

Checklist to study the Morphological features of Scyphozoan and Cubozoan Jellyfishes

1	Tentacles present on umbrella (on margin or underside) (or) Tentacles lacking on umbrella	
2	Umbrella almost spherical (or) Umbrella not spherical	
3	Umbrella without prominent white spots (or) umbrella with numerous prominent white spots	

4	Mouth-arms with stout finger-like appendages (or) Mouth-arms with long and slender fi laments basally	
5	Tentacles on underside of umbrella (or) Tentacles on margin of umbrella	
6	Tentacles in a wide band around underside of umbrella; medusae large (or) Tentacles in 8 U-shaped clusters on underside of umbrella	
7	Colour of the Umbrella	
8	Umbrella cuboid or not cuboid	
9	Umbrella higher than a hemisphere (or) Umbrella decidedly fl attened.	
10	Tentacles round noodles like or pasta like flattened	

CHAPTER 28

Demersal Fishes - Life History Studies and Resource Assessment of fishes

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Demersal fishes are those, which are bottom dwelling fishes and fishes that are close to the sea bottom. Demersal fisheries have been a major source of human nutrition and commerce for thousands of years. Main objective of the demersal fishery is nothing but human consumption. Compared with pelagic resources like mackerel and sardine, the demersal fishes are relatively large and high value species. Since the fishes are mostly associated with sea bottom, these are also known as ground-fish fisheries. Deep-water fisheries are mostly featured by some of their major characteristics like slow growth, longevity, and low reproductive output that may be the reasons for the low sustainability towards the high level of fishing pressure. The intensity of fishing activity throughout the world, including demersal fisheries, has increased rapidly over the past century, with more fishing vessels, greater engine power, better fishing gear, and improved navigational aids. Many demersal fisheries are now overexploited and all are in need of careful assessment and management if they are to provide a sustainable harvest.

Studies revealed that the fishing pressure definitely leads to the fluctuation in the fish stocks and may leads to the changes in the life history of fishes. It has long been hypothesized that fishing can cause phenotypic changes in exploited fish populations. Targeted fish stocks may show some fluctuations in connection with their population and ecosystem. High level of fishing pressure on a fish stock may leads to the quickly maturing individuals which in turn leads to the population shift (young, small individuals maturing quickly).So fishing can increase fluctuations in fishes and their ecosystem, particularly when coupled with decreasing body sizes and advancing maturation characteristic of the life-history changes induced by fishing.

Since the fishing pressure and ecosystem differs for each stock, one fish stock may exhibit differences in life history parameters of other stocks of same species. Differences among these life history parameters among groups of fishes have long been used as a basis for identification of fish stocks. Age, Growth and mortality characteristics are the most frequently used life history parameters to identify the fish stocks. Like other life history parameters, age and size based parameters are strongly influenced by environmental factors, although the effects of these factors from exploitation is inherently difficult.

Fishing may drive life history changes via at least two different mechanisms.

(i) Fishing may induce plastic changes in life history traits. For example, heavy fishing pressure often leads to drastic declines in population size, which in turn can lead to the reduction of the intraspecific competition, and thus survivors may get a better individual growth rates.

(ii) Fishing may induce evolutionary (genetic) changes in fish stocks by selecting against particular life histories. Targeted fish stock may directly correlate with the fishing pressure by the removal of particular age and size group by the use of specifically selected fishing gears. Survivor may get genetic changes with respect to the life history traits like maximum length (small individuals mature early and so the maximum size will be reduced), Longevity (mature early and dies early). Age at first maturity (early matures).

However, many of the commercially exploited fish populations show not only demographic shifts in population structure but also trends in fish life-histories towards earlier maturation and declining adult body size. While such changes can be also induced by increasing water temperatures, most of the observed trends correlate positively with fishing pressure.

The morphological and reproductive characteristics, population sizes, and genetic frequencies of species are linked to their environments by natural selection. Different stocks of same species inhabiting different environments show different patterns of life history characteristics. The relationship among habitat, ecological strategies, and population parameters has been termed r and K selection (MacArthur and Wilson 1967) and/or optimal life histories (Gadgil and Bossert 1970). This body of theory is based on the assumption that natural selection operates on these characteristics in order to maximize the number of surviving offspring produced.

In fisheries biology, the value of comparative studies of life history parameters (fecundity, longevity, maturation age, maximum total length, parental care, and spawning season duration**)** has long been recognized (Holt 1962; Beverton 1963; Cushing 1971; Alverson and Carney 1975). These life history parameters should vary in a consistent pattern which can be predicted from the theory of r and K selection. This is not a particularly new or unique idea in fisheries biology. Beverton and Holt (1959) investigated a positive relationship between body size and life span and between mortality and growth rates. Cushing (197 1) suggested that there is a negative relationship between degree of density dependent regulation and fecundity. Alverson and Carney (1975) have suggested a positive relationship between body size and the time when a cohort maximizes its biomass. All these empirical observed trends in life history parameters are consistent with r and K selection.

The criterion for success in natural selection is the number of surviving offspring that a parent produces (Crow and Kimura 1970). Therefore, the best reproductive strategy is a compromise between two conflicting demands:

(i) production of the largest possible total number of offspring (r selection),

(ii) Production of offspring with the highest possible fitness (K selection).

The particular point of compromise for any species will be a function of the selection factors operating on that species and would be that species' position on the r and K continuum.

Life history traits

Life-history traits are often related through trade-offs that define the life-history strategy of a given organism (Winemiller et al. 2015). Such life-history strategies are used to shed light on the evolution of organisms, as well as the environment in which the species occur (Charnov et al. 2013).

Fisheries based on more r selected species:

- will be more productive. They can be fished at younger ages and at higher levels of fishing mortality. Given a minimum population size, these fisheries should also have a quicker recovery from overfishing.
- are likely to be strongly influenced by physical forces in the environment. Relationships of this type, e.g., between anchovies and upwelling, should be important considerations in management plans for these species.
- are likely to be of a boom and bust nature. Although in some years catches in these fisheries will be very large, they will be characterized by erratic production levels.
- are likely to have less range of variation towards growth rates, reduced age at first maturity, and greater fecundity at age.

Fisheries based on more K selected species

- will have a high maximum yield per recruit, but there will be fewer fish. These fisheries would be more susceptible to overfishing and stock depletion.
- are much more likely to have sophisticated life history mechanisms, which would have to be recognized in a management plan. (These mechanisms might include parental care systems such as nesting or live births, mating systems, or territoriality.)
- are much more likely to have strong interspecific relationships.
- in contrast to the boom and bust nature of **r** selected fisheries, will be characterized by relatively stable population sizes.

Conclusion

The r and K continuum is a model and as such occurs only in an idealized sense. The idealized r selected species occurs in an ecological vacuum with no density effects and no competition. The idealized K selected species occurs in a completely saturated ecosystem where densities are high compared with carrying capacities and competition for resources is intense. The problem of applying this model to any real situation is not a trivial one. Species are not simply subjected to a single selective pressure, or even to a single set of selective pressures. Because of this, r and K concepts should only be applied in a comparative sense between groups of species that have some degree of functional similarity. No species is r selected or K selected in an absolute sense; it is only relatively more r selected or K selected than some other reference species. This theory will only have value in a situation where the population dynamics of one member of a species group are fairly well understood. In short, r and K selection seems to have been an important evolutionary trend on marine fish populations. The result of patterns in population parameters which arise from r and K selection is that different management strategies would be appropriate. The value of this approach is likely to be in initial stages of development of a fishery. As a fishery becomes more developed and information that is more specific becomes available, a more refined management strategy would become possible.

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CHAPTER

29

Life History Assessments of Fishery Resources as Applied in Biodiversity Valuation and Conservation

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In fisheries biology, life history parameters of fishes are routinely assessed as they can be employed to understand the dynamics of the resource and aid in fisheries management. Species inhabiting different environments will have the life history characteristics suitable for that particular ecosystem. In this, the principle of natural selection operates which ensures that maximum number of fittest individuals survive and flourish in that particular ecosystem. The relation between habitat, ecological strategies and population parameters give rise to an organism classified as either an *r* strategist or *K* strategist (Adams, 1979). The theory of *r* and *K* selection is based on two important assumptions. Firstly, the fitness of the offspring is positively related on the resources invested on it and secondly, there is only a fixed and limited amount of resources available. The best reproductive strategy is therefore a compromise between these two conflicting demands and determines the species position on the *r*-*k* continuum. The *r*- *k* continuum is a model and the *r* or *k* selection of any species is not in an absolute sense but only on a relative basis with reference to other species, and useful for comparison in an ecological context. Fisheries based on more *r* selected species will be more productive and can be fished at younger ages and higher levels of fishing mortality than *k* selected species. Also, provided there is a minimum population size and a spawning stock, their chances of recovery from overfishing are higher. Fisheries based on more *K* selected species will have a high maximum yield per recruit but fewer fish. Also, these fisheries will be more susceptible to overfishing and stock depletion. The *K* selected species will also have complex life history stages that require mating, live birth, territoriality and nesting (eg. sharks , rock fish, cichlids, catfish etc.).

Table1. Differentiation of species based on life history traits

Trait	*r* selected species	*K* selected species
Growth rate	high	low
Maturity	early	late
Fecundity	high	low
Body size	small	big
Maximum size	small	big
Maximum age/Life span	low	high
Age/Length at first maturity	low	high
Natural (pre-recruit) mortality	high	low

Fisheries based on *r* selected species are more likely to be influenced by the environment (eg currents, upwelling, rainfall, sea surface temperature) and typically show a ‘boom and bust’ nature with highly fluctuating catch trends. In contrast, the fisheries based on more *K* selected species have relatively stable populations and catch levels. Prediction of future catches from such fisheries is also possible with some degree of accuracy, if information can be gathered through larval surveys, prior to their recruitment into the fishery.

Overfishing and habitat loss are considered the two main threats to marine fish biodiversity.

The marine fish abundance and biodiversity trends can be assessed for quantitative (population size) and qualitative changes (species composition, age/size groups occurring). Within species, population size decline and related life history changes including that occurring at genetic level are being used in marine fish biodiversity assessments (Hutchings and Baum, 2005). Now there is increased awareness about the need for fisheries management using a holistic, ecosystem based approach. Fish biologists and fishery resource managers are increasingly depending on approaches that can identify those fish species or populations that are at greater risk for serious overfishing and population decline within the given ecosystem. Productivity Susceptibility Analysis (PSA) is one such approach that has been used in countries such as Australia and USA. In this procedure, the risk of overfishing is evaluated in a two dimensional context of 'productivity' and 'susceptibility' scores based on a suite of attributes for each stock/ species evaluated. The 'productivity' attributes are an indicator of the potential of the stocks for growth and recovery from perturbations. It can include 'r' (intrinsic rate of population increase), Maximum length/ age reached (L"), von Bertalannfy growth coefficient (K), estimated natural mortality (M), measured fecundity, breeding strategy, recruitment pattern, length/age at first maturity and mean trophic level among others. The 'susceptibility' attributes are related to fishing (catchability, geographic distribution, vulnerability to gears employed, economic value of the species caught etc) and management strategies (catch limits set or not, spawning stock biomass or proxies used for regulation of fishing mortality etc.) in place. Each attribute for the 'productivity' and 'susceptability' index is ranked on a score of one to three from low to high. Appropriate weightages can also be given. For consistent scoring and comparison of studies across regions, the ranges for the attributes have to be set taking into account the particular ecosystem studied and the species available therein. These results can then be appropriately used by fishery managers and policy makers to derive the maximum sustainable benefits from that particular ecosystem.

CHAPTER

30

Lobster and Deep Sea Shrimp Resources and Biology

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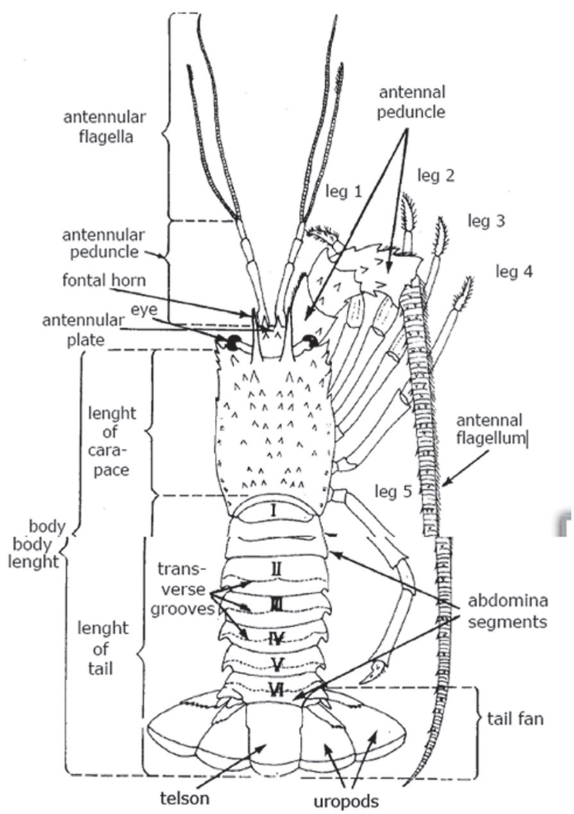
Shellfish systematics is the most unique one in Fisheries Science in view of its importance and implications in diversity. The systematic zoology is the science that discovers names, determines relationships, classifies and studies the evolution of living organisms. It is an important branch in biology and is considered to be one of the major subdivisions of biology having a broader base than genetics, biochemistry and physiology. The shellfish includes two highly diversified phyla i.e. phylum ***Arthropoda*** and phylum ***Mollusca***. These two groups are named as shellfishes because of the presence of ***exoskeleton made of chitin in arthropods*** and ***shells made of calcium in molluscs***. These two major phyla are ***invertebrates***. They show enormous diversity in their morphology, in the habitats they occupy and in their biology. Phylum Arthropoda includes economically important groups such as lobsters, shrimps, crabs. Taxonomical study reveals numerous interesting phenomena in shellfish phylogeny and the study is most indispensable for the correct identification of candidate species for conservation and management of our fishery resources and aquaculture practices. On the whole taxonomic study on shellfishes furnishes the urgently needed information about species and it cultivates a way of thinking and approaching of all biological problems, which are much needed for the balance and well being of shellfish biology as a whole.



general shape (dorsal view) of a spiny lobster
(Panulirus sp.Xno rostrum, no pincers)

Lobster Resources

Lobsters are among the most prized of fisheries resources and of significant commercial interest in many countries. Because of their high value and esteemed culinary worth, much attention has been paid to lobsters in biological, fisheries, and systematic literature. They have a great demand in the domestic market as a delicacy and is a foreign exchange earner for the country.

Key to species of *Panulirus* recorded off the Indian coast and the island groups, Andaman Nicobar Island and the Lakshadweep Islands

1. Abdominal segment 2-5 with the transverse grooves……………………………………2 Abdominal segments 2-5 without transverse grooves or with indistinct grooves in juveniles only……………………4
2. Margin of transverse abdominal grooves with squamae varying from well developed and even in size to minute and irregular in size. Overall colour ranges from brownish-red in specimens with large squamae to olive green in specimens with minute squamae ……………………………………***P.homarus***
3. Abdominal segment 2-5 with the transverse grooves……………………………………2 Abdominal segments 2-5 without transverse grooves or with indistinct grooves in juveniles only……………………4
4. Margin of transverse abdominal grooves with squamae varying from well developed and even in size to minute and irregular in size. Overall colour ranges from brownish-red in specimens with large squamae to olive green in specimens with minute squamae ……………………………………***P.homarus***

   Margin of transverse abdominal grooves with no trace of squamae…………..3
5. Antennular plate (between the stridulating organs) with 2pairs (4) of subequal principle spines, fused at their bases. Supraorbital horns rounded in cross section. Overall colour olive-black………………………***P.pencillatus***

   Antennular plate with 1 pair (2) of equal principle spines; supraorbital horns flattened bilaterally. Overall colour purplish-red with abdomen covered with conspicuous white spots……………………………***P.longipes***

   Antennular plate with 1 pair of equal spines; white bands on each abdominal segment. Legs with white spots. Colour Olive green…………………***P.polyphagus***
6. Conspicuous transverse white band posteriorly on each abdominal segment. Legs with longitudinal white stripes, juveniles have white antennae. Overall colour black and green……………………………***P.versicolor***

   No transverse white band on abdominal segments but above each pleural spur is a conspicuous white spots. Legs with irregular transverse mottling, no longitudinal stripes. Overall colour bluish green…………………………***P.ornatus***

***Panulirus homarus homarus* (Linnaeus, 1758)**

Biology: Maximum total length 31cm, carapace length 12cm. Average total length 20 to 25cm Major fisheries are on the southeast and southwest coast of India. The commercial fishery at Muttom, Kanyakumari district was found to be largely supported by 1st and 2nd year animals. At a given carapace length females are heavier than males. Females attain functional maturity at a carapace length (CL) of 55mm. Males attain maturity at 63mm CL on the basis of allometric growth of III walking leg. Peak breeding season is from November to December.

Genus *Puerulus* Ortmann, 1897

Key to species (after Berry, 1969)

1. Two teeth between frontal horns and the cervical groove

   1a. Median keel of carapace with 5 post-cervical and 2 or 3 intestinal teeth. Fifth pereopod of male not chelate.............................. *P.sewelli*

Biology: Maximum total body length 20cm, maximum carapace length about 8cm. Average total length about 15 cm. The species was commercially exploited along the southwest and southeast coast of India. A catch rate of 200-300kg/hr was reported from vessels opening off Mandapam. January to April is the peak period of abundance. During 1998-2000, 524t were landed at Sakthikulangara, Kollam, and Kerala. The sizes of *P.sewelli* ranged from 76-80mm to 176-180 TL in Males and from 81-85mm to 176-180mm in females. 26% of females were found in mature/berried stage. Due to coincidence of peak breeding and the fishery, the breeding population has been heavily exploited. The species has been overexploited and the current landing is around 2 tonnes/annum from Quilon Bank.

Family: Scyllaridae Latreille, 1825

Key to Identification of the family

Antennal flagellum reduced to a single, flat plate which forms the sixth and final segment of the antenna. The shovel-like appearance of the antennae is responsible for the name shovel-nosed lobster

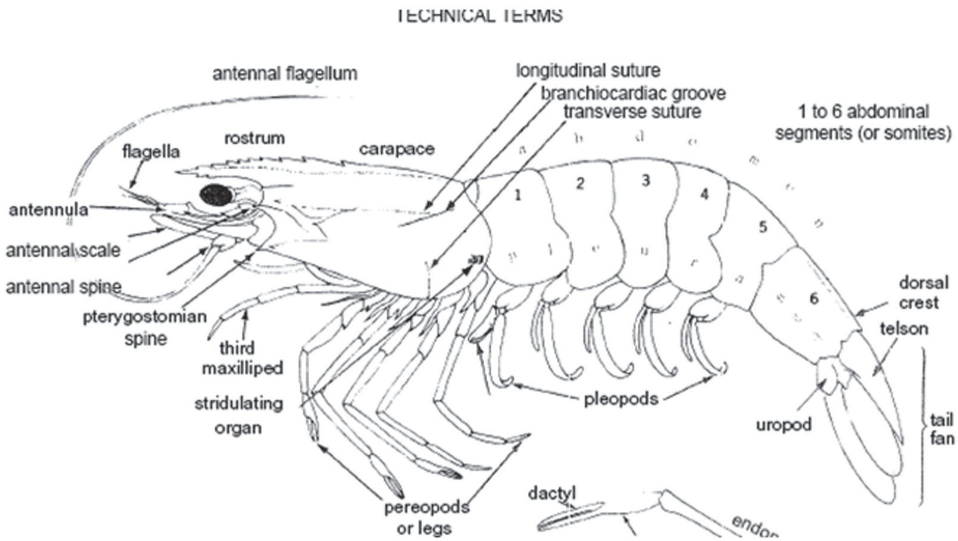
***Thenus unimaculatus* Burton & Davie, 2007**

Biology: Maximum total body length about 25cm; often appears as bycatch in trawl; also caught in gillnets. At Kollam, Kerala peak fishery was observed from November to February. Total length varied between 61-230 mm in males and 46-250mm in females. Length at recruitment (Lr) was 48mm. Absolute fecundity varied from 14750 to 33250 mature eggs (Radhakrishnan *et al.,* 2013).

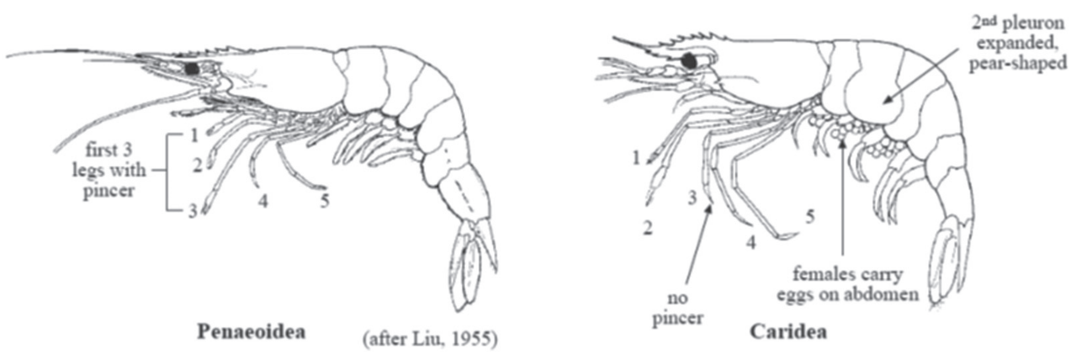
Shrimp Resources

Shrimp resources are available both from inshore and from offshore waters. As the fish resource from inshore waters remained static during the last two decades, fishing pattern underwent several changes in the previous decade, leading to the exploitation of deep sea resources either with deployment of large sized vessels or modified medium/small sized vessels. Deepwater shrimps appear to have a world-wide distribution in tropical waters. They have been caught in surveys using baited traps in depths between 200 m and 800 m off continents and at 200- 500 m depth in the Indian Ocean.

Deep sea decapod crustaceans constitute one of the dominant high price groups of invertebrates in the marine fishery sector of Kerala although the structure and organization of their community



are not well known as that of coastal penaeid prawns. In view of the increasingly prominent role played by deep sea prawns and prawn products in the economy of the country, the taxonomic identity of various species exploited from the deep sea fishing grounds off Kerala is an essential prerequisite for the sustainable development and management of deep sea prawn wealth of Kerala. The deep sea prawns landed at various harbours of Kerala is an assemblage of wide array of species representing various families, the prominent being *Pandalidae, Aristeidae, Solenoceridae and Penaeidae while family Oplophoridae* contributes to only a minor portion of the deep sea trawl catches in Kerala.



Key to the deepsea prawns of Penaeidae, Pandalidae and Oplophotidae

Penaeidae

1. Inner border of the antennular peduncle with a setose scale; Podaobranchiae absent……….2

   No setose scale on the inner border of the antennular peduncle; podobranchiae present; pleurobranchia on 10-13 segments reduced to mere papillae…..***Aristeus alcocki***

2. Exopodite of the external maxillipeds large, absence of a brachio-cardiac sulcus in the branchiostegal region……………………………………………………………………………………………3

3. Symmetrical petasma; no basal spine at 3rd maxilliped…………………………………………….4

4. A long fissure on either side of the carapace throughout the entire length; rostrum not glabrous and less then 1/3rd the length of carapace…………...***Parapenaeus investigatoris***

   No fissure on carapace wall; rostrum glabrous,as long as carapace…….***Penaeopsis jerryi***

Pandalidae

1. Carapace hard and rigid with longitudinal carinae; 2nd pair of pereiopods unequal…….***Heterocarpus***…….3

   Carapace smooth without a longitidinal carinae; 2nd pair of periopods Carapace equal…2

2. 3rd abdominal somite unarmed or with fixed postero-medial tooth; terminal segment of 2nd maxilliped broader than long, attached strip like to penultimate segment with its longer side……***Plesionika***……5

3. 3rd abdominal tergum without spines, length of 6th abdominal segment less than 5th…4

   3rd abdominal tergum ends in a sharp spine dorsally; 6th segment more than double the length 5th………………………….. ***Heterocarpus woodmasoni***

Oplophoridae

1. Rostrum with atleast as many dorsal as ventral teeth; abdomen with 4thand 5th somites usually armed with posteromesial tooth; left mandible with incisor process not tapering sharply toward opposable margin, armed with 9-14 subacute teeth……………………………. ***Acanthephyra***

2. Abdomen with 6th somite shorter than 5th (not including posteromesial spine); telson simply pointed posteriorly, not terminating in spinose endpiece; 3rd maxilliped and 1st pereiopod with broadly compressed rigid exopods……………………………………..***Oplophorus***

3. Carapace with strong carina extending from branchiostegal spine to branchial region; abdomen with posterior margin of 3rd somite not distinctly excavate either side of posteromedian tooth…. ***Acanthephyra fimbriata***

Penaeid shrimps

***Aristeus alcocki* Ramadan 1938**

Diagnostic characters: Large size red abdominal rings. Rostrum in female long and slender upper margin curved downwards till distal end of 2^{nd} segment of antennular peduncle. Rostrum in males much shorter and seldom surpassing tip of antennular peduncle, armed with three teeth above orbit; **and no teeth on ventral side, lacks hepatic spine, upper antennular flagellum very short, Eyestalk with a tubercle.** Petasma simple, membranous, right and left halves united with each other along the whole length of dorsomedian with a papilla-like projection directed posteromedially. Thelycum represented by a shield shaped plate directed anteroventrally bordered by an oblique ridge on either side.

Colour: Pink with reddish bands on the posterior border of all abdominal segments.

Fishery & Biology: The catches were mainly composed of females and their size ranged from 78 mm to 188 mm in total length. The size distribution showed unimodal pattern with majority in size groups 146-165 mm. The males, which were very poorly represented in the catches were relatively smaller in size and their total length varied from 67 mm to 110 mm.

Distribution: Indian Ocean; Arabian Sea and Bay of Bengal, at depth of 350-450 m off Quillon and Alleppey.

***Solenocera hextii* Wood-Mason & Alcock, 1891**

Family : Solenoceridae

Diagnostic characters: Flatenned rostrum with 7 teeth on dorsal side and no teeth on ventral side of the rostrum. Postrostral carina sharp but not laminose. Antennular flagella with red and white bands. The spines on the cervical groove situated ventral to the posteriormost rostral tooth which is well developed. The characteristic 'L' shaped groove on either side of the branchiostegal region is also clearly defined.

Colour: Pink to red

Distribution: Found all along the east and west coast of India at depths between 250 to 547 m.

***Metapenaeopsis andamanensis* (Wood-Mason, 1891)**

Family: *Penaeidae*

Diagnostic characters: Rostrum more or less horizontal and straight with 6 to 7 teeth on dorsal side and no teeth on the ventral side. Lower antennular flagellum longer than the upper, much longer than the entire antennular peduncle but 0.7 times the carapace length. 3^{rd} pereopod surpass the rostrum by the length of the entire chela. Assymetrical petasma. 3rd maxilliped and 1st pereopod with a basal spine, distal fixed pair of spines on telson.

Colour: Pale pink to red

Fishery & Biology: The total length of males varied from 67 mm to 115 mm and that of females from 68 mm to 130 mm.

Distribution: A penaeid prawn commonly encountered in the trawl catches at all depths ranges upto 400 m and was obtained from all areas.

Penaeopsis jeryii **Perez Farfante, 1979**

Family: *Penaeidae*

Diagnostic characters: Dagger shaped rostrum with teeth on dorsal side of the rostrum. Specimen appears to be pale red in color with white bands on the body. Cervical groove very prominent, antennal scale as long as rostrum. Thelycum trilobed and sub elliptical in structure.

Fishery & Biology: Size range of female specimens ranged from 74-115 mm and males ranged from 70-110 mm.

Distribution: All along the southwest coast of India particularly off Cochin, Quillon and Alleppey at depth of 275-350 m

Caridean / Non-Penaeid shrimps

Heterocarpus woodmasoni Alcock, 1901

Family : *Pandalidae*

Diagnostic characters: Carapace with 2 longitudinal crests on each side, extending over full length of carapace – post antennal crest and branchiostegal crest. A conspicuous elevated, sharp tooth at middle of dorsal crest of 3rd abdominal segment, telson bears 5 pairs of dorsolateral spinules besides those at the tip.

Fishery & biology: Size in the catches ranged from 72 to 135 mm in total length but dominated by 111-120 mm size groups in both the sexes. The fertilized eggs on the pleopods and the head-roe are light orange and this colour stands out in contrast with the pink colour of the prawn. The berry becomes greyish in advanced stages of development.

Distribution: Andamans, Southwest of India off Cochin and Alleppey at depths of 250-400 m**.**

Heterocarpus chani Li, 2006

Diagnostic characters: The teeth on the dorsal crest and the rostrum together vary from 8 to 10. Teeth on the rostrum proper varying from 2 to 4 and 13-15 on ventral side. The dactyli of the 3 posterior legs short, median carination of the 3rd abdominal tergum is quite prominent. Carapace with 2 longitudinal crests on each side, extending over full length of carapace- post-ocular crest and branchiostegal crest. Post antennal crest very short.

Fishery & biology: The size of the individual prawn varied from 67 to 140 mm in total length and the catches were represented by all groups of the females. Males are mostly in 90-100 mm size groups. The colour of the berry is light **orange** and turns dirty grey as embryo develops.

Distribution: Southeast and Southwest coast off Cochin, off Alleppey at depths of 250-400 m. immature specimens were found in greater numbers in shallow waters while the bigger prawns seemed to prefer deeper grounds beyond 350 m.

Plesionika quasigrandis **(Bate, 1888)**

Pandalidae

Diagnostic characters: Rostrum upturned at the tip. Rostrum is armed with 46 teeth on the dorsal side and 31 teeth on the ventral side., very long slender legs, Telson is double the length of the 5th abdominal somite. Lower antennular flagellum longer than the upper and about 5.4 times the carapace length. 3rd maxilliped extends beyond the antennal scale by the length of its dactylus. Second pereopod exceeds the tip of antennal scale by its chela and 1/8 length of carpus. Minute tubercle on the dorsal surface of the carapace at about 1/6th of its length from the hinder edge which corresponds in position to the small blunt median spine which is present in all the specimens.

Colour: Body pale red in colour

Fishery & biology: The size of this prawn in the catches ranged from 63 to 125 mm but the size groups 95-110 mm in both sexes predominated. Berry is greenish-blue in colour with ovoid shape of fertilized eggs.

Distribution: In Indian waters this species is known to occur in south-east and south-west coast of India abundantly noticed from Quilon and Mangalore regions from the depth of 250-400 m.

Plesionika semilaevis **Spence Bate, 1888**

Diagnostic characters: Rostrum very long pointed with 7-9 dorsal teeth including 2-5 teeth on carapace posterior to the level of orbital margin while ventral margin of the rostrum is armed with 34-56 teeth.

Fishery & biology: The size of this prawn in the catches ranged from 71 to 120 mm in males and 80 to 130 mm in females. The modal lengths for males and females were at 90-95 mm and 96-100 mm respectively. Berry is deep blue in colour in the early stages and to light grey in advances stages of development.

Distribution: In Indian waters this species is known to occur along the south-west coast particularly through out the Kerala coast abundantly noticed from Quilon and Alleppey regions from the depth of 200-450 m.

Family : Ophlophoridae

Ophlophorus gracilirostris Alcock, 1901

Diagnostic characters: Carapace with dorsal carina extending to the posterior margin. Rostrum very long almost equal in length to the carapace. Branchiostegal spine quite distinct, with a well-defined keel, spine on the 3rd abdominal tergum very much longer than those on the 4th and 5th. In the male the anterior border of the first abdominal somite is bilobed with the posterior lobe more pronounced and angular.

Distribution: Arabian Sea, Bay of Bengal, Andaman Sea and Hawaiin Islands, Southwest of Cochin, off Alleppey 300-450 m

***Acanthephyra fimbriate* Alcock & Anderson, 1894**

Diagnostic Characters: The carapace is without a straight ridge or carina running on the entire length of the lateral surface i.e., from the hind margin of the orbit to the posterior edge of the carapace. Rostrum long, upcurved with 5 to 6 teeth on the dorsal side and only one tooth on the ventral side of rostrum. Dorsal carina of 3rd to 6th abdominal somites ending in pointed spines. Sometimes the posterior spine on the sixth somite may be absent. Telson generally more or less truncated at the tip and laterally it is armed with spines. Eyes are well pigmented. Incisor process of the mandible is provided with teeth throughout the entire length of its cutting edge. Pereopods are not abnormally broad and flattened. Exopods of the third maxilliped and all pereopods are neither foliaceous nor rigid.

Distribution: Southeast and Southwest coast of India

Acanthephyra sanguinea Wood-Mason, 1892

Diagnostic Characters: Rostrum longer than carapace with 7 dorsal and 5 ventral teeth, extending much beyong the tip of the antennal scale. Branchiostegal spine small, forming a small projection on frontal border of carapace and without a carina. Surface of carapace finely pitted as in all the species of the purpurea group. Dorsal carinae of 3rd to 6th abdominal somites ending in pointed spines, that of 3rd somite the longest and of 4th and 5th of equal size and smallest. Four pairs of dorsolateral spines present on the telson.

Distribution: Southeast and Southwest coast of India

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CHAPTER

31

Marine Mammals and Fisheries Interactions

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Introduction

The term marine mammal includes members of five different mammalian groups: Cetaceans (whales, dolphins, and porpoises), Pinnipeds (seals, sea lions and walruses), Sirenians (manatees, dugongs, and sea cows), Sea otters and Polar bear. Marine mammals are probably one of the best sentinel organisms in aquatic and coastal environments because many species have long life spans and have extensive fat stores that can serve as depots for anthropogenic toxins. Many marine mammals are at the top of the food chain, putting them at risk of accumulating high levels of contaminants in their tissues over their lifetime or assimilating biotoxins present in their prey. These toxic levels indicate not only the health of the marine mammals, but also the condition of the ecosystems. Marine mammals have also been used in navy. Navy trains these animals to perform tasks such as ship and harbour protection, mine detection and clearance, and equipment recovery. The Indian seas support a variety of marine mammals, which include baleen whales, toothed whale, dolphins, porpoise and dugong. Stranding and sighting records show that the Indian seas are a habitat for 26 species of cetaceans and one species of sirenian (sea cow). Of the 26 species of cetaceans six are Mysticeti (baleen whales) and the rest are Odontoceti, which includes Delphinidae, Physeteridae, Kogiidae, Ziphiidae, Phocoenidae and Platanistidae. Until the year 2003, knowledge of marine mammals of India was restricted to incidental catch of various species in fishing gear.

Conservation of Marine Mammal in India

Between 2003 and 2012, the Central Marine Fisheries Research Institute (CMFRI) undertook organized research work on marine mammals and conducted extensive visual sighting cruises on-board FORV *Sagar Sampada* in the Indian seas and contiguous seas to explore diversity, distribution and ecological characters of this mega fauna. Since the commissioning of FV *Silver Pompano*, this process had become more intense and elaborate. The total number of sightings in the Indian seas was estimated at 650, which comprised 8700 individuals, belonging to 18 species. All the 27 species of marine mammals in the Indian seas are protected under Wildlife (Protection) Act 1972. While the Act has significantly reduced intentional capture of marine mammals, incidental capture in fishing gears is a cause for concern. Stranding records can be used as an indirect means to monitor the status, distribution, seasonal abundance and fishery interaction of marine mammals. It has been documented that 380 stranding records are available in the Indian seas in the last 60 years (Vivekanandan and Jeyabaskaran, 2012). About 85% of the strands have been reported by researchers from CMFRI. Recurring stranding events are also reported frequently along the entire Indian coast. Conservation management action plans are important for maintaining and restore the distribution, abundance and diversity of marine mammals in the Indian EEZ. It is important to recognize that marine mammal conservation can take place only with the support and participation of fishermen. Conservation of marine mammals could be achieved by integrating the agenda into fisheries regulatory mechanisms. There is a need to create awareness among fishermen and the public on the importance of mammals in the marine ecosystems, their status and threats, and the need for conservation.

Based on the collected information, the conservation status of Indian marine mammals was classified based on IUCN Red list criteria and the results are given in Table. 1.

Table 1. Marine mammals of India & Conservation Status

No	Common Name	Species name	IUCN Status	India Status*
1.	Blue whale	*Balaenoptera musculus*(Linnaeus, 1758)	Endangered	Endangered
2.	Fin whale	*Balaenoptera physalus*(Linnaeus, 1758)	Endangered	Endangered
3.	Bryde's whale	*Balaenoptera edeni* Anderson, 1878	Data Deficient	Data Deficient
4.	Common Minke whale	*Balaenoptera acutorostrata* Lacépède, 1804	Least Concern	Data Deficient
5.	Humpback whale	*Megaptera novaeangliae* (Borowski, 1781)	Least Concern	Data Deficient
6.	Sperm whale	*Physeter macrocephalus* Linnaeus, 1758	Vulnerable	Vulnerable
7.	Pygmy sperm whale	*Kogia breviceps* (de Blainville, 1838)	Data Deficient	Data Deficient
8.	Dwarf sperm whale	*Kogia sima* (Owen, 1866)	Data Deficient	Data Deficient
9.	Cuvier's beaked whale	*Ziphius cavirostris* Cuvier, 1823	Least Concern	Data Deficient
10.	Indo-Pacific beaked whale	*Indopacetus pacificus* (Longman, 1926)	Data Deficient	Data Deficient
11.	Short-finned pilot whale	*Globicephala macrorhynchus* Gray, 1846	Data Deficient	Data Deficient
12.	Killer whale	*Orcinus orca* (Linnaeus, 1758)	Data Deficient	Data Deficient
13.	False killer whale	*Pseudorca crassidens* (Owen, 1846)	Data Deficient	Data Deficient
14.	Pygmy killer whale	*Feresa attenuate* Gray, 1874	Data Deficient	Data Deficient
15.	Melon-headed whale	*Peponocephala electra* (Gray, 1846)	Least Concern	Data Deficient
16.	Irrawady dolphin	*Orcaella brevirostris* (Gray, 1866)	Vulnerable	Vulnerable
17.	Indo-Pacific humpbacked dolphin	*Sousa plumbea* (Osbeck, 1765)	Near Threatened	Least Concern
18.	Rough-toothed dolphin	*Steno bredanensis* (Lesson, 1828)	Least Concern	Data Deficient
19.	Risso's dolphin	*Grampus griseus* (Cuvier, 1812)	Least Concern	Least Concern
20.	Bottlenose dolphin	*Tursiops aduncus* (Ehrenberg, 1833)	Data Deficient	Least Concern
21.	Pan tropical spotted dolphin	*Stenella attenuate* (Gray, 1846)	Least Concern	Data Deficient
22	Spinner dolphin	*Stenella longirostris* (Gray, 1828)	Data Deficient	Least Concern
23.	Striped dolphin	*Stenella coeruleoalba* (Meyen, 1833)	Least Concern	Data Deficient
24.	Long beaked common dolphin	*Delphinus capensis* Gray, 1828	Data Deficient	Least Concern
25	Finless porpoise	*Neophocaena phocaenoides* (Cuvier, 1829)	Vulnerable	Near Threatened
26	South Asian River dolphin	*Platanista gangetica* (Roxburgh, 1801)	Endangered	Endangered
27	Sea cow	*Dugong dugon* (Müller, 1776)	Vulnerable	Endangered

* Status assigned based on sighting surveys conducted by the CMFRI during the years 2003 - 2012 under the project "Studies on marine mammals of Indian EEZ and the contiguous seas" funded by CMLRE, Ministry of Earth Sciences, Government of India

Marine mammals – fisheries interaction

The marine mammal – fisheries interaction is a major cause for concern. Mechanized fishing was introduced on a commercial scale in India in the mid 1960s. Since then, the fisheries sector has grown rapidly. Marine fisheries census carried out by CMFRI in 2005 shows that there are 58,911 mechanized fishing craft along the Indian coast operating trawl net, gillnet, lines, dolnet and purseseines. The efficiency of fishing vessels has increased, resulting in longer sea endurance, extension of fishing to oceanic waters and the introduction of larger and efficient gear. The growing number and efficiency of mechanized boats have increased the chances of fishing gear – marine mammal encounters. Unfortunately the incidental kills of marine mammals have not been regularly monitored in India. However, it is natural to expect that the incidental kills of marine mammals, especially those of small cetaceans, would have increased with the proliferation of mechanized fishing fleet.

Bycatch of Marine mammals

Competition between cetaceans and fishermen for commercially important fishes is a major cause of concern for cetacean population. Extensive fishing by gillnet in mechanized boats has increased 'bycatch' and driven many species to vulnerable state.'Bycatch' refers to animals that become hooked, trapped, or entangled in fishing gear deployed with the intention of catching something else, i.e. the catching is inadvertent or accidental. The accidental entanglement in fishing gear that causes these marine mammals to become trapped underwater so they cannot reach the surface to breathe.In India, fishermen use the dolphin calf for consumption and adults are used as bait for hook and line fishery for sharks and tuna. The International Whaling Commission (IWC) estimated at least 3,08,000 dolphins and porpoises are killed in bycatch each year in the world's oceans. The World Conservation Union (IUCN) identified bycatch as one of the serious threats to the marine mammals.IWC estimated that >40,000 cetaceans are killed annually in Sri Lanka artisanal gillnet fisheries. Gillnets and purse seines operated from motorized boats caused the entire boycott. At the same time dolphin-fishery interactions cause a loss in revenue by damaging the gear and loss of captured fish.

The Marine Fishery data of the country is collected from all the maritime states through a well-defined stratified random sampling design. Marine mammals do not form a regular by-catch, hence there is no continuous data. However, staff of CMFRI stationed in various parts of the east and west coasts report on stranding and entanglement as and when such incidences occur. The FEMD/CMFRI has collated the information on marine mammals and the data pertaining to entanglement is given below.

Fishing related mortality of cetaceans

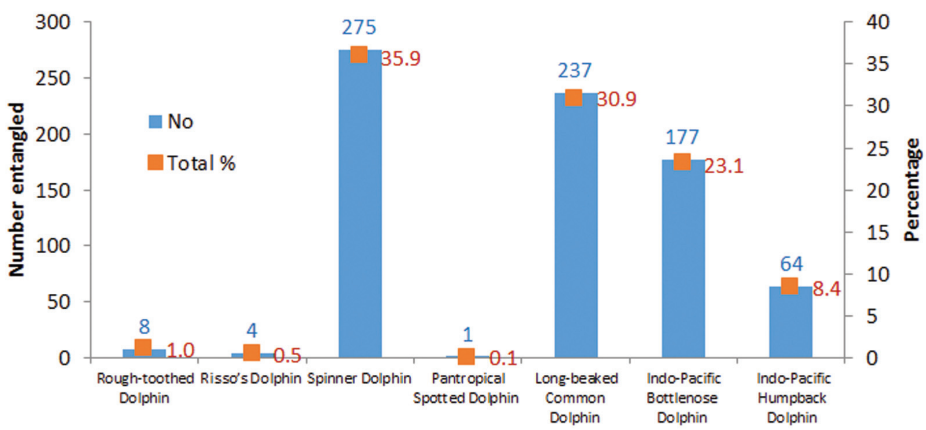
All the marine mammals of the region are afforded protection under the Indian Wild Life Protection Act, 1972. Records on entanglement of marine mammals in fishing gears were collected and analysed for the period 1950 to 2015. It was observed that gill nets are responsible for 98.8% of the mortalities. Occasional reports on incidental catch / entanglement in trawl, purse seine, shore seine and long line has also been recorded. This became a problem from 1970s though the first report in 1953 was that of an incidental catch of porpoise in a dol net along Gujarat.The average entanglement of porpoises is less than 0.69 per year along the Indian coast and that of dolphins is about 11.7 per year. However, these are released back to the sea immediately since the fishermen are aware about the Act on the marine mammals. According to the survey conducted among fishermen dolphin population has increased and this has negatively affected their fishing activities. Damage to gear and financial loss to mend this is a problem cited by gill netters of South India.

Porpoises:

A total of 45 porpoises have been found to be caught by fishing nets along Karnataka (34nos), Kerala (9nos; from gill nets) and one each from Gujarat (dol net) and Tamil Nadu (gill net). Of the 34 nos. from Karnataka, 32 were from gill net and 2 from purse seines. Surveys conducted in Kerala and Karnataka indicate that the porpoises continue to get entangled in gill nets in Karnataka and though this creates problem for the fishermen whose nets get torn, they release them back to the sea most often.

Dolphins:

About 766 entanglements / incidental catch of dolphins in fishing gears has been reported from Karnataka, Kerala, Tamil Nadu and Andhra Pradesh. Seven species of dolphins, such as Spinner Dolphin (275nos), Long-beaked Common Dolphin (237 nos.), Indo-Pacific Bottlenose Dolphin (177 nos.), Indo-Pacific Humpback Dolphin (64nos.), Rough-toothed Dolphin (8 nos.), Risso's Dolphin (4 nos.) and Pantropical Spotted Dolphin (1 no) were reported in the fishing gear related mortality along the Indian coast (Fig 1). Spinner Dolphins were reported in all the four south Indian states while others were mostly caught along the Kerala –Tamil Nadu fishing gear operations. Highest fishing related mortality were reported from Kerala (526 nos.) followed by Tamil Nadu (231 nos.). In Karnataka fishing related mortality was low (2 nos); spinner dolphin and Indo Pacific humpback dolphin one each. Only one species has been reported from Andhra Pradesh Spinner dolphin (5 nos.) and from A& N islands, beaked common dolphin has been reported.



During this century, the number of dolphin species reported in fishing related mortality **reduced to four**; only species such as Risso's Dolphin, Spinner Dolphin, Indo Pacific humpback dolphin Pantropical spotted dolphin have been reported. Entanglement of porpoises has been reported from Karnataka and Gujarat during this century.

Conclusion

Competition between cetaceans and fishermen for commercially important fishes is a major cause of concern for cetacean population. Conservation management action plans are important for maintaining and restore the distribution, abundance and diversity of marine mammals in the Indian EEZ. The information gathered from the majority of strandings has not been sufficient to determine the cause of the stranding. As a way forward, we suggest that sighting data may be combined in the future with stranding data as a more comprehensive tool to understand ecological linkages. Understanding of marine mammals requires population dynamics study. Marine mammal sighting data is required to understand the causes of these changes e.g. abundance of food, predation, levels of harvest, habitat availability, and how they affect reproduction and survival of individuals in the population. It is important to recognize that marine mammal conservation can take place only with the support and participation of fishermen. Conservation of marine mammals could be achieved by integrating the agenda into fisheries regulatory mechanisms. There is a need to create awareness among fishermen and the public on the importance of mammals in the marine ecosystems, their status and threats, and the need for conservation.

CHAPTER

32

Importance of Molecular Taxonomy in Fishery Biology Investigations

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Fitness and survival of diverse organisms to a particular environment is dependent on the unique biological attributes of a species. The inherent genetic variation within species and populations provides the necessary impetus to thrive in the presence of dynamic environmental forces. Understanding the genetic and morphological diversity is the key to ensure sustainability of ocean resources, identify adaptive evolution patterns and manage ocean resources. Molecular taxonomic investigations have undergone tremendous advancements in the last decade due to the advent of sequencing methods. The power and precision associated with molecular taxonomic investigations have contributed immensely to the advancement in knowledge in many areas of biological science.

Several molecular markers are in use for understanding intra- and inter- specific patterns of diversity in marine populations and they can be characterized as Type I and II. When a marker is associated with genes of known function they belong to Type I category and when associated with genes of unknown function, they belong to Type II category.

Type I markers

Allozyme markers are type I markers as they are associated with genes of known functions. DNA encodes allozymes and genetic variation at the level of enzymes can be detected using allozyme electrophoresis. Allozymes are protein variants which originate from allelic variants which differ in electric charge and these variations could be detected using electrophoresis. Allozymes are codominant markers expressed in heterozygous individuals in a Mendelian fashion. Information regarding single locus genetic variation can be gathered using allozyme analysis which can answer many questions regarding intra- and inter specific diversity of fish populations. To detect variations in allozyme pattern, allozymes have to extracted from tissues following standard protocols and variations detected through electrophoresis in an acrylamide or cellulose acetate gel. A single band will be present if individuals are homozygous and double bands when individuals are heterozygous. Allozymes have been extensively studied and used for many investigations due to their simplicity and cost effectiveness as any kind of soluble protein can be used for allozyme analysis. Many numbers of loci can be screened at a time using allozyme markers. Major limitations with the use of allozyme analysis include requirement of large amount of tissue which impedes its use with smaller organisms like larval forms. The tissue sampling method is invasive and hence every time the fish has to be sacrificed and tissue stored cryogenically. Point mutations in nucleotide sequences could not be detected using protein electrophoresis as such mutations may not result in change in the amino acid composition. In spite of all these limitations, allozymes have been widely used for fishery biology investigations like fish systematic, population genetic structure, conservation genetics and forensic applications.

Mitochondrial DNA markers

Mitochondrial DNA is found in the cytoplasm inside organelles called mitochondria and hence they are considered as non- nuclear DNA. Mitochondrial DNA can be considered as a haploid genome which is maternally inherited and transcription takes place as one single unit. Mitochondrial DNA is not subjected to recombination events, selectively neutral and present in multiple copies in each cell. It is easy to isolate mitochondrial DNA from any tissue or blood sample as they are physically separated from the cell's DNA. Detection of population bottlenecks and hybridizations is easy using mitochondrial DNA as effective population size is smaller than nuclear DNA due to its maternal inheritance.

Molecular taxonomic methods using mitochondrial DNA employ either RFLP based length polymorphism or sequence variations to detect differences in patterns of genetic diversity. RFLP is based on the length polymorphisms generated on digesting mitochondrial DNA with restriction enzymes and visualizing these polymorphisms electrophoretically. RFLP has been widely used to understand species specific patterns in many marine fishes.

Sequencing the amplified region of mitochondrial DNA has become very popular now after the emergence of sequencing technologies. Several universal primers are available based on conserved sequence regions so that they can be applied universally to any tissue type. Inter specific comparisons can be carried out using slow evolving gene regions and intra specific comparisons using fast evolving gene regions. The gene, Cytochrome C Oxidase 1 (around 600bp) is being used as the universal barcode for species specific comparisons as it is a slow evolving region. It is highly conserved across a wide range of taxa. D-loop region, the only non-coding region is fast evolving and used for intra-specific or population comparisons. In addition, cytochrome b and ND-1 and ND-5/6 regions are also being used for intra-specific comparisons. Mitochondrial DNA genes find widespread application in fish systematics and population genetics.

Nuclear DNA markers

Nuclear DNA markers can be categorized as arbitrary and specific depending on the gene regions to be amplified.

Arbitrary markers

Arbitrary markers include; RAPD, Random Amplified Polymorphic DNA and AFLP, Amplified Fragment Length Polymorphism. RAPD makes use of an arbitrary marker to amplify regions of genomic DNA and exhibits very high amount of polymorphism. This marker does not require any knowledge of regarding gene or genome and so it is very fast, cheap and efficient. But RAPD markers lack reproducibility and repeatability and many products are simultaneously generated. Homozygous and heterozygous states cannot be distinguished based on these markers and slight changes in amplification conditions bring about variations in band patterns. AFLP markers employ both RFLP and RAPD techniques. Two restriction enzymes are used to digest genomic DNA followed by ligation of double stranded nucleotide adapters to the ends of DNA fragments which will be the primer binding sites for subsequent amplification by PCR. Primers which are complementary to the adapter and sequences at the restriction site with additional nucleotides at the 3' end can be used as selective agents which can amplify a subset of ligated fragments. Polymorphisms along with presence or absence of DNA fragments are detected on polyacrylamide gels.

Specific markers

Variable number of tandem repeats is parts of DNA repeated tens, hundreds or thousands of times within nuclear genome of eukaryotes. They are repeated tandemly, varying in number at different loci of the genome and individuals. Repetitive DNA can be classified as minisatellite and microsatellite DNA. Minisatellite DNA are loci with repeats of length varying between 9-65bp and microsatellite DNA with repeats 2-8bp. Microsatellites are found abundantly in the genome as compared to minisatellites and they are widely used in population genetic analyses. Minisatellites are of two types; multilocus and single-locus. Multilocus minisatellites consist of tandem repeats of 9-65bp with length varying between 0.1 to 7kb. Minisatellite loci can be used for parentage analyses whereas they are less useful for population genetic analyses. Their mutation patterns are very complex and hence interpretation is very difficult for population genetic analyses. Most of the research works are concentrated on single locus minisatellite probes which are successful in detecting population genetic variations. Other applications of minisatellite loci include forensics, parentage analysis, understanding mating success and confirmation of gynogenesis.

Microsatellites are simple repeated sequences in the genome which are highly variable. These loci can be used as markers and are seen every 10kbp of the genome. They are very useful in genome mapping and population genetic investigations. These loci are highly variable, selectively neutral, do not code for proteins and hence the amount sequence divergence may be directly related to the time since separation. Microsatellites evolve faster at a rate of 10^{-3}-10^{-4} mutation/ generation and are inherited in a Mendelian fashion. They are considered as codominant markers. Due to the high level of polymorphism, they are very popular. Cross amplification with primers developed for closely related species minimizes cost associated with microsatellite detection and characterization. The procedure of microsatellite amplification involves, extraction of DNA, amplification using specific primers and visualization of bands in PAGE gel. Automated genotyping by using labeled primers has made the analysis of size polymorphisms accurate and fast. The presence of null alleles and stutter bands is the major limitation while using microsatellites. Null alleles occur due to mutations at primer binding sites which will decrease accuracy in parentage or relatedness analysis and so discarding loci showing null alleles is the best option. Stutter bands are formed due to slipped strands mispairing during PCR or inadequate denaturation of amplification products. Stuttering is relatively less with tri- and tetra- nucleotide repeats. Microsatellite markers can be used in fisheries and aquaculture for detecting genetic structure of populations, conservation of biodiversity, phylogenetic investigations, phylogeographic studies, understand impacts of stocking and hybridization. It can also be employed for forensic identification of individuals, mapping of genome, determination of kinship and patterns of behaviour.

Single nucleotide polymorphisms arise in the genome due to single point mutations like insertions/deletions and transitions or transversions. Point mutations produce divergent alleles with alternative bases at a specific nucleotide position and these alleles are estimated to understand intra- and inter- specific diversity patterns. SNPs are considered as the most abundant polymorphism in the genome which can be detected using PCR, microarray chips or fluorescence technology. SNPs are described as next generation markers in fisheries and can be widely applied for population genetics and genomics investigations.

DNA microarrays are small glass microscope slides, nylon membranes or silicon chips which can hold many immobilized DNA fragments in a standard pattern. A reporter probe of known sequence can be matched with DNA from target sample which is of unknown origin. Microarray can also be used for construction of species specific DNA probes which could be subsequently used for identification purposes. DNA of the target samples has to be labeled with fluorescent molecules and hybridized to the DNA of the microarray. A fluorescent signal will be emitted when hybridization is positive which can be detected using appropriate fluorescence scanning/imaging equipment.

Expressed sequence tags can be generated using random cloning of cDNA and they can be used for identification of genes and analysis of expression by means of expression analysis. It is possible to make fast and reliable analysis for the genes expressed in particular tissue types under specific physiological or developmental stage. cDNA microarrays can be used to identify differentially expressed genes in a proper way. In addition, ESTs can also be used for linkage mapping.

Molecular markers in fishery biology investigations

1) To understand inter and intra specific variations

The extent of divergence in DNA or genes is considered as the baseline for species level differentiation and the variability in evolution among taxa should also be considered while making decisions. Mixed catches, larval forms, endangered and threatened animals caught illegally, stranded cetaceans and processed fish products can be identified up to species level using molecular markers as morphological identification is not possible with these samples. Molecular markers can be used for fish stock characterization or identification of sub-species.

2) Phylogenetic and Phylogeograhical studies

Phylogenetic studies focus on historical processes affecting species relationships whereas phylogeographic studies focus on processes affecting geographical distribution. Mitochondrial DNA markers can be utilized effectively for phylogenetic and phylogeographic investigations. Based on mitochondrial DNA information, the evolutionary history of groups of fishes can be reconstructed and vital knowledge on historical demography obtained. In addition, conservation units and ecological patterns also deduced. Mitochondrial DNA has been used as a powerful tool to infer intraspecific phylogenetic patterns in many marine fishes.

3) Identification of genetic structure between and within populations

Identification of stock structure of fish populations is very vital for fisheries management and conservation. Stocks are subpopulations within species which may be reproductively isolated and exhibiting different physiological and behavioural patterns. Mitochodrial DNA as well as microsatellite markers are widely used for inferring genetic stock structure of marine fish populations. Morphological and meristic information should be combined with genetic information so that a comprehensive picture of subpopulation structure is obtained. Identification of subunits from mixed fisheries or origin of stock components is also possible using molecular tools.

4) Genetic tagging/marking

Individual fishes can be marked for tracking movement or migration, understanding population size or contributions of distinct stock to mixed fishery. Since physical tags are not heritable, they cannot be employed for generations. Genetic tagging by tracking a rare allele in individuals of populations over generations will be beneficial to understand the contribution of hatchery programme on harvest and identify migrants from different regions.

5) Forensic investigation

Molecular markers are very effective in identifying dead or stranded fishes and preserved or canned items as morphological identification is not possible in them. Certification of fishery products and detection of illegal trading of fish and fishery products is also possible using molecular forensic technologies. Molecular tools also could be used for monitoring deliberate or accidental release of fishes/organisms to natural waters.

6) Studying the trophic relationships

Determining trophic relationships within ecosystem is very essential for any ecological study and data on diet composition is crucial towards achieving this aim. It is difficult to identify diet components up to species level using morphological features alone as partial or complete digestion will destroy key morphological features. DNA can be extracted from partially digested samples and diet components studied using molecular markers.

7) Ancient DNA to deduce historical evolutionary relationships

Preserved samples in museums, fossil remains, archaeological finds and other unusual sources can be utilized for retrieval of DNA sequence information using several methods. Several such investigations have improved our understanding with respect to evolutionary relationships among different taxa.

8) Applications in aquaculture

Molecular markers can be effectively used in aquaculture for; selective breeding and genetic improvement, finding quantitative trait loci, identifying inbreeding events, genetic identification of hatchery stocks, progeny assignment, marker assisted selection, understanding the effects of ploidy induction and gynogenesis. Molecular markers have wide range of applications in disease diagnosis. PCR based kits are available for detection of many diseases like white spot syndrome virus (WSSV), infectious pancreatic necrosis virus (IPNV), viral nervous necrosis virus (VNNV), channel catfish virus (CCV), infectious hematopoietic necrosis virus (IHNV) and viral hemorrhagic septicemia virus (VHSV).

Conclusion

Molecular markers are excellent tools to enhance fisheries and aquaculture productivity and ensure sustainability. Markers should be selected cautiously so as to improve the quality of the output. Next Generation Sequencing technologies are revolutionizing the field of biology and the future of aquaculture and fisheries will depend on the penetration of these technologies to this vibrant sector.

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CHAPTER 33

Biology of Sea Cucumbers: An Assessment Towards Conservation

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Introduction

Sea cucumbers popularly called holothurians belong to the phylum Echinodermata, which is a distinct phylum in the animal kingdom. Echinoderms are almost exclusively marine, with a variably shaped body which is subdivided into ten areas. They are characterised by the possession of radial symmetry (generally pentamerous), an intradermic skeleton consisting of closely fitted plates, articulated plates, or ossicles, and a peculiar water vascular system of tubes filled with fluid. Holothurians have an orally-aborally elongated body (Fig.1). The body is formed like a short or long cylinder, with the mouth (at the anterior end) encircled by tentacles, and the anus (at the posterior end) often edged by papillae. Holothurians often lay on the substrate with their ventral surface or trivium, formed by the radii. This creeping sole bears the locomotory podia, while on the dorsal surface, or bivium, the podia are often represented by papillae. The mouth is terminal or displaced dorsally, surrounded by a thin buccal membrane, and generally bordered by a circle of tentacles (Fig. 1). Tentacles are buccal podia containing extensions from the water vascular system. Their number varies between 10 and 30, generally being a multiple of five.

There are known to be roughly 1000 species of sea cucumber, and six orders make up the class; aspidochirotida, apodida, molpadiida, elasipodida, dendrochirotida, and dactylochirotida with classification based primarily on tentacle form, calcareous ring form, presence or absence of respiratory trees and tube feet and in some cases ossicle form(s). In the Aspidochirotida all tentacles are of the same size, but in the Dendrochirotida some tentacles are generally smaller. The shape of the tentacles differs among the various orders and is used as a key character. In the Dendrochirotida they are dendritic (branching in an arborescent manner) and can reach a large size when extended. The Aspidochirotida and most Elasipoda have peltate tentacles, each with a central stalk. The Apoda have pinnate tentacles, with a central axis bearing series of digitations. The Molpadida have digitate tentacles, consisting of short projections with small terminal fingers. The body surface is thick, slimy in many species and wears warts, tubercles, or papillae. The anus is often displaced dorsally, encircled by small papillae or anal teeth. The colouration varies between species and sometimes also between individuals of the same species. The creeping sole is often brighter and lighter than the dorsal surface.

Sea cucumbers contribute significantly to the community biomass, being a significant benthic invertebrate community, and their biology and behaviour have more significant effects on physicochemical processes of soft-bottom and reef ecosystems. Commercially exploited sea cucumbers, provide a source of income to millions of coastal fishers worldwide and a source of nutrition to Asian consumers (Purcell et al., 2013). The processed product from sea cucumber is called 'beche-de-mer,' in French, 'iriko' in Japanese, 'haisom' in Chinese and 'trepang ' in Indonesian, and has a very high export value to south-east Asian countries. The sea cucumber is an ideal tonic, higher in protein and lower in fat content and rich in nutrients such as vitamins, amino acids, trace metals and minerals (Bordbar et al., 2011). Sea cucumbers are an integral part of Chinese medicine for the treatment of several diseases like body weakness, impotence, debility of the aged, constipation due to intestinal dryness and frequent urination. Recent research indicated their integral parts in biomedical research, as an important source of several bioactive compounds of anti-angiogenic, anticancer, anticoagulant, anti-hypertension, anti-inflammatory, antimicrobial, antioxidant, antithrombotic, antitumor and wound healing properties. Sea cucumbers have a more significant role in ecosystem functioning by contributing to sediment health via bioturbation; recycling of nutrients; influencing seawater chemistry; bolstering high biodiversity through symbiotic associations; and forming pathways of energy transfer in food chains etc.

Biology of sea cucumbers

Anatomy

The body of an aspidochirote sea cucumber is elongated along the aboral/oral axis. The body wall is thick and well developed. It consists of a non-ciliated epidermis, connective tissue dermis, circular and longitudinal muscles, and a ciliated peritoneum. Muscles control the tentacles, and large longitudinal muscles used in body movement and contraction attach in layers to the calcareous ring forming the majority of the mass of the pharyngeal bulb (Fig 1). The mouth at the centre of the anterior end is surrounded by a thin peristomial membrane (buccal membrane). The body wall is a thick layer of collagenous connective tissue. Most of the thickness of the wall is the connective tissue dermis. There is a thin epidermis outside the dermis. Calcareous ossicles (Fig.1) are present in the outer layer of the dermis of most cucumbers. The shapes of ossicles vary with species and age, and they are essential in taxonomy (Slater and Chen,2015).

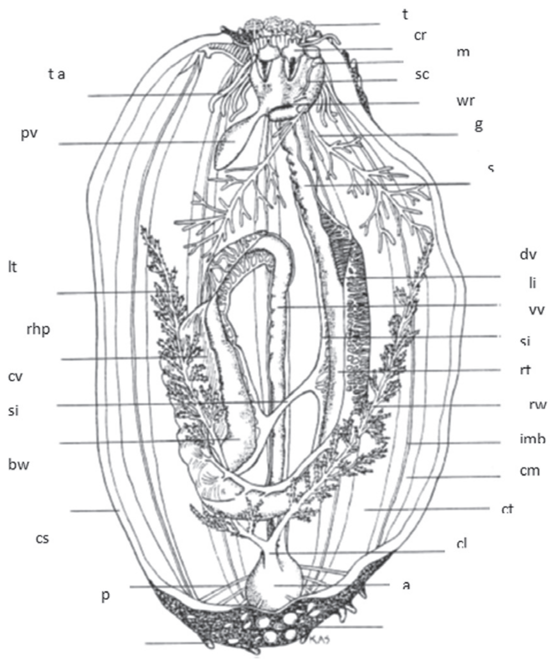

Fig. 1. General sea cucumber anatomy. t, tentacle; cr, calcareous ring; m, madreporite; sc, stone canal; ta, tentacular ampulla; wr, circular water ring; g, gonad; Pv, Polian vesicle; s, Stomach; dv dorsal intestinal haemal vessel; lt, left respiratory tree; li, large intestine; vv, ventral intestinal haemal vessel; rhp, respiratory-haemalplexus; si, Small intestine; cv, cross-ventral intestinal haemal vessel; rt, right respiratory tree; rw, radial water canal; lmb, long muscular band; cm, circular muscle; ct, common respiratory tree trunk; cl, cloaca; cs, Cloacal suspensors; a, anus; p, papilla. Adapted from Hyman, (1955) and Sewell (1987).

The dermis comprises of the central part of the body and concerning commercial exploitation, the thickness, tissue texture, and taste of the dermis are essential elements influencing their value in the international market. The muscular layer consists of transverse and longitudinal muscles. Its longitudinal muscles are in five strong bands under nervous control. Light stimulus induces muscular contraction causing the body to shrink to a half or as little as one-third its standard size when relaxed.

The calcareous ring is a vital organ. It consists of 10 large ossicles, encircles the anterior end of the gut, supports the ring canals of the water vascular and hemal systems, provides a mechanical base for the buccal podia, and is the site of insertion of the longitudinal body wall muscles. The ring diameter is about one-tenth of body length, which limits the size of food particles, particularly at an earlier juvenile stage.

Reproductive System

In contrast to other echinoderms, the reproductive system of holothurians consists of a single gonad or genital gland. The gonad is attached to the dorsal mesentery through which the gonoduct or genital stolon opening passes, leading to the outside by the gonopore (genital orifice) or a genital papilla. Holothuroids are gonochoric but show no anatomical sexual dimorphism. The gonad composed of either two tufts of tubules, or only one tuft in many species of the family Holothuriidae whose free ends may extend throughout much of the coelom. The gonad becomes enlarged and increasingly branched as maturity is reached before spawning. Following spawning, the gonad tubules are often entirely reabsorbed in temperate species. Observations of tropical species indicate that gonads are present at all times in varying degrees of development (Conand 1993). The sexes are generally separated and show little dimorphism unless in the period of maturing. In most species, the mature gametes are freely released into the seawater. The spawning behaviour, observed in many Aspidochirota species, involves an upright posture of males and females followed by swaying back and forth, while the gametes are being released. The sea cucumber populations are generally present in 1:1 sex ratio. The oocytes of most commercial species of sea cucumbers are usually under 200ìm in diameter, and more or less neutrally buoyant when released in the water column. However, commercial species from temperate regions may possess large yolk buoyant oocytes that can measure up to 1mm in diameter. Reproductive cycles are variable among species, but most tropical species have biannual spawning activity, and fewer species have annual spawning activity. In addition to sexual reproduction, about ten species reproduce asexually by transverse fission by dividing at the middle of the body; both halves re-grow vital organs and form clones of the original individual (Conand,1981; Hyman,1955).

Digestive System

The mouth opens into the pharynx, then to an oesophagus, a stomach, all of which are small structures, and a very long intestine. The intestine consists of three portions, a descending, an ascending, and finally a descending loop which connects to both the rectum and the cloaca opening outwards through the anus. The cloaca opens to the exterior via the anus, which is closed by the anal sphincter. The respiratory trees extend from the cloaca into the coelom. When present, respiratory trees are connected to the cloaca. The oxygenated water enters the body by these water lungs, which are found in all orders except the Apoda. Cuvierian tubules, which are sticky tubules attached to the base of the respiratory trees are present in several species of Aspidochirota, are generally considered as defensive structures and can be expelled through the cloaca towards the source of irritation.

Respiratory System

The respiratory system consists of tubular structures spring from the anterior part of cloaca near the entrance of the large intestine, which ascends anteriorly into the coelom. The right and left respiratory trees are highly branched evaginations of the wall of the cloaca extending along the body cavity into the perivisceral coelom and are surrounded by coelomic fluid. The trees are anchored to the body wall by delicate connective tissue threads, and the left respiratory tree is intimately associated with the intestine. In addition to the respiratory trees, the entire skin of the sea cucumber has a respiratory function. The skin is capable of sufficiently performing all respiratory function in case of the evisceration of the respiratory trees.

Habitat, growth and longevity

Holothurians are found throughout all oceans, at all latitudes, from the shore down to abyssal plains. They are usually benthic (living on the bottom); some species live on hard substrates, rocks, coral reefs, or concealed under rocks or coral slabs or tucked into crevices, as epizoites on plants or invertebrates; most of the species inhabit soft bottoms, on their surface or in the sediment.

Sea cucumbers are not amenable to conventional tagging methods (Purcell and Kirby, 2006), hence, in general, it is difficult to estimate the growth rate in sea cucumbers (Conand, 1990). However, growth rates in the sea cucumbers have been evaluated by modal progression analysis, genetic fingerprinting, and release and monitoring of juveniles. Purcell and Simutoga,(2008) estimated that *Holothuria scabra* is reaching the size at first maturity (<180 g) in a year but take another couple of years to achieve an acceptable market size. The calculated age at early sexual maturity varies between two and five years for most commercially viable species however significantly faster maturation rates have been reported from commercial aquaculture production (Eriksson et al. 2011; Hamel et al. 2001b; Herrero-Perezrul et al. 1999; Yamana et al. 2010). In general, the longevity of sea cucumbers have been estimated around 10 to 15 years but some species like *Stichopus chloronotus*, it has been estimated around five years (Conand and Sloan, 1989).

Food and feeding

Generally, holothurians exhibited two types of feeding mechanisms. The dendrochirotes are plankton feeders, and they are called suspension feeders, which sweep tiny organisms like plankton and detritus adhering to tentacles through mucous secretion (Hamel and Mercier, 1998). They stretch their tentacles to the fullest extent into the seawater or may sweep them over the surface of the substrates. Minute organisms and detritus adhere to the tentacles through mucus secretion will be engulfed with tentacular contraction. The non-dendrochirotes are deposit feeders, shovel the surrounding substrate into their mouths employing the tentacles and burrowing forms swallow the substrate as they advance through it. They consume detritus, bacteria and diatoms mixed with sediments on the seabed (Conand, 2006).

Life-Cycle

Generally, the aspidochirotes sea cucumbers are broadcast spawners exhibiting seasonal spawning behaviour. Most of the species have biannual spawning, and some have annual spawning behaviour that coincides with the summer months in temperate species. Eggs are generally small and transparent, floating between 100 and 200ìm in most species. Whereas those that are brooded tend to enormous size and yolky content and hence free larval stages are omitted. Cleavage is equal, holoblastic and of the radial types with tiers of cells in line with each other. The pelagic gastrula and early auricularia larvae develop rapidly to feed on microalgae for a period ranging between 12 and 40 days before mature auricularia form the transient doliolaria stage, which exists for less than 24 h before metamorphosis to pentactula and ultimately early juvenile stage.

Conservation of sea cucumbers in India

In India, sea cucumbers have been distributed in Gulf of Mannar, Palk Bay, Lakshadweep and Andaman and Nicobar islands. Mainly the fishery was existed in Gulf of Mannar and Palk Bay and serves as an income source for thousands of fishers in this area. Like in many other Indo-Pacific countries, indiscriminate exploitation and inadequate management measures have caused over-exploitation of sea cucumber resources in the Indian waters, as evidenced from the decrease in export, decreased the size of the specimen fished and absence of certain species from the fishery. The Ministry of Environment, Forests and Climate Change, Government of India implemented a ban in 1982 on export of 'beche-de-mer ' below 75 mm length. The legislation was not much success as the sea cumber fishery was not organised. The Ministry imposed a blanket ban in 2001 which was implemented strictly since 2003, on the fishing and trade of sea cucumbers from Indian waters by listing all holothurians under schedule I of the Indian Wildlife (Protection) Act, 1972. The ban has caused severe impact on the livelihood of poor fishers of Gulf of Mannar and Palk Bay who subsist on the fishery and processing of sea cucumbers from this region. The affected fishermen and traders made repeated representations to the government to lift the ban, citing the negative impact of the prohibition of their livelihood. The ministry entrusted the Zoological Survey of India, to evaluate the effect of the ban and recovery status of sea cucumber stock in the Gulf of Mannar and Palk Bay during 2006 and 2011. The study indicated poor recovery and less improvement of the sea cucumber stock, after implementation of the ban (Venkitaraman, 2006; Venkataraman et al., 2012). The resource surveys and interview surveys conducted by CMFRI under BOBLME indicated that the status of sea cucumber population in the Gulf of Mannar and Palk Bay could be improved if regulatory measures with participatory co-management are followed (BOBLME, 2015). In this context, research on sea cucumber stock restoration and sustainable livelihood based on the culture of commercially important sea cucumber species through hatchery system along with the implementation of suitable fishery regulatory measures have been emphasised in Indian conditions. (Asha et al., 2017).

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CHAPTER

34

Applications of Fishery Biology Data for Mariculture

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Fish production was previously heavily dependent upon capture fishery and in particular the marine resources. However, the capture fishery cannot be expected to be a perennial protein donor. Moreover, a substantial portion of the marine catch is being utilized for making industrial products which are not directly consumed by man. Therefore, a viable alternative by which fish production could be increased through a popularized bio technique, called aquaculture. Aquaculture may be defined as the "farming and husbandry of economically important aquatic animals and plants under controlled conditions". The aquaculture sector is indeed remarkable for its diversity in operations, encompassing a very wide range of farming practices, species, environments and production systems, often with very distinct resource use patterns. The sector is also highly fragmented, ranging from smallholder ponds or cages providing a few kilos of fish per year to international companies with annual turnover in excess of USD1 billion. Indeed, despite having achieved good progress in terms of expansion, intensification and diversification, the aquaculture sector is confronted with a set of key issues and challenges that needs to be proactively addressed in order to contribute to green growth. In order to develop a sustainable aquaculture practice the various aspects to be carefully studied include: 1. Site selection, 2. Species selection, 3. Selection of culture types based on many factors as species combinations like monoculture, poly culture etc., culture systems like static systems like pond culture, tank culture or running water systems like race ways, cage culture systems or circulatory systems etc. all these requires a thorough knowledge on the biology of the species to be cultured. The following general factors should be considered when selecting a species for a successful aquaculture venture:

- Knowledge on biology, ecology, and life history
- Knowledge on reproductive culture methods
- Possibility of captive breeding and closing the life cycle under controlled farming conditions
- Ability to culture at high population densities in artificial holding facilities
- Ability to consume and efficiently grow on artificial formulated diets
- Ability to mimic the natural life cycle in a controlled environment
- Attainability of market size within economically feasible period of time
- Low vulnerability to pathogens

The ideal aquaculture species possesses all the above characteristics. However few if any species are ideal. More often there is some compromise in terms of these characteristics.

Why do we do research in fish biology?

Biological studies are the basic studies in any living organisms comprising plants or animals. It is a requirement in various branches of life sciences; and therefore of course fisheries sciences also for any type of management and/or culture of any living organisms or species or groups. Apart, gaps in biological knowledge often prevent progress in sustainable development process like aquaculture practices. Likewise, limitations in knowledge about any life species' physiology and its requirements during different life stages can hamper various stages of its culture from seed production to farming. The application of scientific knowledge for the development of the fishing industry lies in an intimate knowledge of the biology of fishes. Without proper knowledge of the life, habits and behaviour of fishes, it would not be possible to do any aquaculture practices for its increased production or plan, control and manage the resources in a satisfactory manner. Reviewing the process over the past 50 years, the rapid growth in aquaculture is clearly a result of developments in fish biology and its various applications like genetics, molecular biology, biotechnology etc. As a multidisciplinary subject the roles and mechanisms of fish phylogenies, development, growth, reproduction and behavior, and thereby exploiting the biotechnology applicable to genetic breeding and disease prevention, fish biology and biotechnology has provided the innovation and technology for rapid development of the aquaculture industry. Biology is the basis of all biotechnological applications and without biological base no manipulations are possible.

Site selection: The success of an aquaculture project depends to a large extent on the proper selection of the site to be developed into a fish farm or hatchery. Proper siting of aquaculture facilities is critical to reducing environmental and social impacts, and to improving long-term operations. The major factors to be considered for the site selection includes: 1. Ecological factors and 2.Biological & operational factors. Before a site can be selected for a project, the following should be ascertained: species to be cultured, its ecological features, tolerance limits, resources available, availability of stocking materials (spawners, fry or fingerlings), compatibility of the species etc. If we want to do mariculture we have to select an area with full saline waters; or area where plenty saline waters can be brought.

Species selection: The choice of suitable species for aquaculture often is a balance between biological knowledge and economic necessities. The biological knowledge required to allow a successful culture of a species is manifold and needs thorough considerations of the applicable conditions. Prior to selecting a species for culture or for a (business) project, it is important to consider the species' biological requirements and the economics and market potential. At present, about 240 fish species are reared in aquaculture (among them about 60 marine species). Many novel aquatic varieties that have played a major role in aquaculture are the results of comprehensive and systematic studies on the biological characteristics of these species. Not all fish species are suitable for aquaculture. By the same token, some cultivable species are more appropriate for large-scale, commercial aquaculture rather than for small-scale operations, as exemplified by the high-value shrimps, the production of which can hardly be undertaken profitably on a small scale. Also, some species are best cultured using specific types of enclosures; for example, penaeid shrimps are best cultured in fish ponds rather than in fish pens and certain species are more acceptable in certain countries than in others. The choice of species for culture depends on a number of factors including the availability of suitable sites for culture, the biological characteristics of the indigenous or introduced/exotic species, their suitability for culture, and their acceptability in the local or international markets, and the availability of technology and other requirements for their culture.

Air breathing fishes in areas where water availability is less or in marshes and in this condition culture of other fishes are not possible. Similarly fresh water fishes only can be cultured in in areas where nothing other than fresh water is available. Cold water fishes require plenty oxygen supply and can live only in Cold Water areas.

The following general factors should be considered when selecting a species for a successful aquaculture venture:

(i) It must withstand the climate of the region in which it will be raised. Thus, purely marine fishes like cobia; carangids etc. need high saline waters during its culture. Pure freshwater fishes cannot live in even brackish water systems. Similarly the rearing of cold water fish like salmonids and trout is limited to temperate regions or mountain areas of tropical countries because they cannot tolerate warm water with its low oxygen content.

(ii) Its rate of growth must be sufficiently high. Small species, even if they reproduce well in ponds and accept formulated diets, are not the most suitable for rearing. Also, the best culture species are those which are low in the food chain, e.g., plankton feeders, herbivores, and detritivores. Their culture is also least expensive, even on an intensive scale, because they do not need to be given diets which have a high content of animal protein.

(iii) It must be able to reproduce successfully under culture conditions. Species for culture should be able to reproduce in captivity/confinement without needing special conditions that have to be fulfilled, and which give high returns on eggs and fry. Although it is possible to rear species whose reproduction in confinement is not possible at all (e.g., some carps) or whose reproduction under hatchery conditions has not yet been possible on a commercial scale (e.g., milkfish in the Philippines), the sustainability of the grow-out operations is hampered by the seasonal unavailability of wild fry for stocking in fish pens and/or fish ponds.

(iv) It must accept and thrive on abundant and cheap artificial food. Culture species which feed on cheap artificial feeds and give low feed conversion ratios (FCRs) also tend to give very good production rates, thus bringing in better financial returns.

(v) It must be acceptable to the consumer. Even if all the foregoing criteria are met by a candidate species, it is not worth culturing if there is no market for it. It is possible, though, to promote acceptability of or encourage consumption of a particular species to ensure that it will eventually sell in the market. (This was the situation with tilapia in the Philippines prior to the introduction of the bigger-sized, lighter coloured *O. niloticus* in the early 1970s.)

(vi) It should support a high population density in ponds. Social and gregarious species which can grow well to marketable size even under high density conditions in ponds or tanks (e.g., tilapia) are preferable to those which can be grown together in dense numbers only up to a certain age beyond which they eat each other (e.g., pike).

(vii) It must be disease-resistant. Reared fish must be resistant to disease and accept handling and transport without much difficulty. Tilapia is an ideal species for culture because of its high resistance to disease even in highly intensive culture systems.

Taxonomy in aquaculture: It has become clear that taxonomic information is not a luxury – it is a real need in a world with a still-growing human population generating enormous pressure on natural resources. Although the need for taxonomic expertise has never been as pronounced as it is today, this has not translated into training more taxonomists and providing more funding for necessary developments in taxonomy. More and more organisms are shipped around the world and marketed continents away from their origins, thus generating an increased need for global fish identification tools to provide reliable information to consumers, customs officers and fishery inspectors. However, worldwide, there exist more than 32 500 species of finfishes and the amount of information required to separate them all is extremely difficult to process; therefore, fish identification is usually conducted at local or regional scales. The increasing globalization of fishery products thus introduces new challenges to the identification of aquatic organisms. For many decades, FAO has been collecting global statistical catch data and analyzing the results in two of its flagship publications: (i) *The State of World Fisheries and Aquaculture* and (ii) the *Review of the state of world marine fishery resources*. The collection of species- and population-specific information for the purpose of sustainable fishery management has a long tradition however also it is very important in the future of aquaculture where species diversification is the need of the hour.

Seed identification: In recent decades, many new and promising techniques for the identification of fishes have emerged, in particular based on genetics, interactive computer software, image recognition, hydro-acoustics and morpho-metrics. In recent decades, many new and promising techniques for the identification of fishes have emerged, in particular based on genetics, interactive computer software, image recognition, hydro-acoustics and morpho-metrics. However, with few exceptions, such advances in academic research have not yet been translated into user-friendly applications for non-specialists and still require further investments to mature into globally applicable tools. In CBA seed identification is another area; especially fishes like mullets it is very difficult to identify the small seeds; and only when it grows only many of the farmers could realize that it is not the species they planned. When it comes to the aquaculture practice it is necessary to identify each and every seed in the beginning itself otherwise it leads to wastage of many things.

Food and feeding: The study of the food and feeding habits of fish is a prime step in any fisheries research program. The dietary analysis of fishes indicates the trophic segregation pattern among the members of the fish community in that area. In general, growth of a fish is influenced by the quality and quantity of food materials available and consumed. This variation is due to changes in the composition of food organisms occurring at different seasons of the year. Thus, any variation in quality and quantity of food materials will affect growth rate of the fish. The qualitative and quantitative variations of natural food materials in a water body are under the influence of several abiotic and biotic factors. These variations could be documented by qualitative and quantitative analysis of gut contents of a fish and or by the estimation of Gastro-somatic index. The study of food and feeding habits of fish help to know what fish eat how it grow it in its habitat and it can be used for feeding the fish while its culture. Feeding habits of fish is also help to know the inter-specific relationship and the productivity of the water bodies. The knowledge of feeding biology helps to produce optimum yield by utilizing all the available potential food of the water bodies properly without any competition. By studying the food and feeding habits, one can understand what program should be follow for the development of the water bodies to produce more fishes. According to Polling (1993), whose studies on food and feeding habits of fish help to determine the ecological condition of fish, niche in the ecosystem, preferred food items. A thorough knowledge on the food and feeding habit of fishes provide keys for the selection of cultivable species and much information is necessary for its successful farming. Food and feeding habits of carps has been a field of interest to fisheries researchers since a long back. The objectives of the dietary studies of *Labeo dyocheilus* include how it lives and grows, what can influence its abundance, distribution and the relative quality of feeding condition. This study has both theoretical and practical importance, so that it can be determine directly the exact type of food that the experimental fish consumes in its natural habits.

Formulation of feeds and feeding schedules for aquaculture is basically based on the food and feeding studies. The nutritional requirement of each and every fish is different and we can understand it based on these studies; and it can be used for the feed formulations in future when mariculture of diverse fishes is possible. We can also use these data for the discovery of alternate sources of protein and food materials for fish feeds. The amount of feed to be given at different stages of development and growth also can be decided based on these studies. It is because of the feeding information made the application of cleaning of nets using pearl spots in brackish waters and rabbit fishes marine conditions in cage culture. Similarly the combinations of fishes in a rearing system can also be decided based on these studies. Therefore snappers are stocked along with sea bass in cages for the complete utilization of feeds as sea bass is a column feeder and snapper feed on leftover food at the bottom of the cages. Another area of similar nature is the cleaner Fish Biology and Aquaculture Applications; where new knowledge on the biology of the utilized cleaner fish species, and provides protocols in cleaner fish rearing, deployment, health and welfare. Cleaner fish are increasingly being deployed in aquaculture as a means of biological control of parasitic sea lice, and consequently the farming of wrasse and lumpfish, the main cleaner fish species in current use in salmon farming, is now one of the fastest expanding aquaculture sectors with over 40 hatcheries in Norway alone. The latest knowledge is presented in a book addresses the questions of sustainability of cleaner fish use in aquaculture, bottlenecks to the optimum production of cleaner fish, and improvements and best practice in on-farm deployment methods, for optimum survival and enhanced welfare of cleaner fish. Contributions from over 60 leading researchers and producers give an exciting mix of information and debate on this subject.

Age and growth: Growth is a complex mechanism, and it is the outcome of the interactions among several biotic and abiotic factors operating on behavioural and physiological processes. The age and growth of fishes are important in the estimation of fish production in terms of quantity, in a body of water in relation to time. In the studies of biological profile of a species, age and growth form the most fundamental aspect. Knowledge of these parameters provides dynamic features of the population and forms the basic key to determine the quantity of fish that could be produced in a fish population against time. The effective management of fish populations as well as developmental activities like aquaculture and their seed production require these types of knowledge on each group/species of fish. Once the addition (weight) in a fish stock in relation to time is determined, the optimum size at age can be fixed for rational exploitation of a fishery. According to

Pillay (1958) a comprehensive study of all available age groups, covering all the seasons and environment of its occurrence is essential in order to obtain a correct picture of nutrition and feeding adaptations. These are the fundamental information required for the selection of species for aquaculture otherwise a fish which take a long time for its growth cannot be selected for aquaculture. The criteria for selection of aquaculture species, first documented by Fan Lee nearly 2500 years ago in a treatise devoted to pond culture of freshwater fishes stated that high priority should be given to species that grow rapidly, are tasty, not cannibalistic, hardy, and inexpensive to culture. Again the information on age growth of a species is very important in aquaculture point of view as it is observed in many species from the mugilidae family which take long time to attain marketable size. Again the age at first maturity is always needed for the breeding and hatchery production of seeds.

Fish population studies: It means a fishery in an area with an associated fish or aquatic population which is harvested for its commercial /recreational value. Fisheries can be wild or farmed. Population dynamics describes the ways in which a given population grows and shrinks over time, as controlled by birth, death, and migration. It is the basis for understanding changing fishery patterns and issues such as habitat destruction, predation and optimal harvesting rates. The population dynamics of fisheries is used by fisheries scientists to determine sustainable yields.

A fishery population is affected by three dynamic rate functions:

- Birth rate or recruitment. Recruitment means reaching a certain size or reproductive stage. With fisheries, recruitment usually refers to the age a fish can be caught and counted in nets.
- Growth rate. This measures the growth of individuals in size and length. This is important in fisheries where the population is often measured in terms of biomass.
- Mortality. This includes harvest mortality and natural mortality. Natural mortality includes non-human predation, disease and old age.

Population dynamics and potential of fisheries stock enhancement is very important in the culture based fisheries. It is a management approach more common in freshwater than in marine systems. Stocking of hatchery fishes has been practiced on a large scale since the mid-nineteenth century, and systematic transfers of wild juveniles probably have a much longer history. Stock enhancement is a fisheries management approach involving the release of cultured organisms to increase abundance and yield of natural stocks. Releases may be carried out on a long-term basis to raise yields above the level supported by natural recruitment, or temporarily to rebuild depleted populations. Stock enhancement describes a continuum of hatchery release and associated harvest regimes, the extremes of which are culture-based fisheries and supplementation. In culture-based fisheries or ranching systems, recruitment is largely or entirely based on hatchery releases, and release and harvesting regimes may be designed to maximize production. By contrast, in supplementation, hatchery fish are released to booster the natural spawning stock. Many marine fish species have experienced dramatic declines in spite of considerable efforts to manage their populations (Pauly et al., 2002; Dulvy, 2003). Despite numerous restocking attempts, wild populations have shown few signs of recovery (Hutchings, 2000), and there are few data demonstrating that releases of hatchery-reared fish actually benefit wild stocks (Hilborn, 1992; Coronado and Hilborn, 1998; Salvanes, 2001).

The population decline of the blue swimming crab *Portunus pelagicus* (Linnaeus, 1758) in Kung Krabaen Bay is currently in crisis due to overharvesting. Apparently, the reproductive status of the crabs is directly affecting larval recruitment. In fact, this problem has not only occurred in Thailand but also in Southeast Asian countries such as the Philippines, Vietnam and Indonesia (National Fisheries Institute Crab Council 2013). The population decline of the blue swimming crab *Portunus pelagicus* (Linnaeus, 1758) is believed to be the result of problems such as overharvesting by efficient fishing gear, destruction of nursery habitat, harvesting ovigerous females and inefficiency of crab management. The Govt. and researchers the studied and found that these difficulties were related to the limited biological and ecological knowledge of *P. pelagicus* among the fishers. Based on these results, a sustainable management program for *P. pelagicus* was proposed as follows: (i) closing the bay during the spawning season, (ii) restoration of the *Enhalus acoroides* seagrass beds, (iii) restocking crab larvae in the bay and (iv) educating and networking all stakeholders to develop a better understanding of the ecology of the crab to support sustainable fishery management in Kung Krabaen Bay. As a result the population of the blue swimmer crabs has increased and exploitations is now started.

Reproductive biology and larval studies: Study of reproductive biology of any fish species is important to get information for successfully continuing its culture. Reproduction is one of the important physiological systems that are crucial in the life cycle of living organisms including fish. The main objective of the reproduction is to maintain the existence of the species and therefore fish have a strategies and tactics to achieve this objective. The reproductive behaviours are important to be studied in relation to know the population dynamic of fishes and their spawning seasons. This information is very crucial in relation to the development of breeding technology for aquaculture and conservation (restocking) purposes. In general the reproduction can be defined as a biological process of living organism to inherit the properties of its parent to their offspring in order to ensure the continuing survival of the concerned species. In fish, there are some tactics and strategies used by fish to ensure their offspring survive. Studies on reproductive biology of fish are crucial needed and a basic requirement to plan a better conservation and management strategies of fishery resources (Ali and Kadir, 1996; Ezenwaji et al., 1998; Brewer et al., 2008; Grandcourt et al., 2009; Muchlisin et al., 2010), examination of basic life-history information and for evaluating the impacts of environmental variability on the dynamics of fish populations (Schlosser, 1990). In addition, information on the reproductive system is essential for the development of the commercial aquaculture of an aquatic species (Muchlisin, 2004).

The reproductive strategy of a fish species is the overall pattern of reproduction common to individuals of within species, whereas the reproductive tactics are those variations in response to fluctuations in the environment (Wootton, 1990; Roff, 1992). Knowledge on the reproductive behavior of fishes is necessary for the development of the commercial aquaculture industry. Study on reproductive biology of any fish species is essential for assessing commercial potentialities of its stock, life history, culture practice and actual management of its fishery5In order to make success in fish culture, it is important to assess the yearly breeding cycle of cultivable fishes. Spawning of fish occurs during a particular phase of the reproductive cycle; some of them breed once annually while others at regular intervals throughout the year. Knowledge of gonadal development and the spawning season of a species allow subsequent studies on spawning frequency. Study of sex-ratio, length at first sexual maturity, cycle of maturation and spawning periodicity etc. are important aspects of reproductive biology study of any fish specie.

CHAPTER

35

How Oceanography Influences Fishery Biology? - A Case of Distribution Differences in Carnivorous and Planktivorous Fishes along the Coastal Waters of Eastern Arabian Sea

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Abstract

Understanding the link between physical oceanographic events and seasonality in catch composition is a critical component in the accurate assessment of climate change impacts in context of fisheries. This remains elusive owing to the lack of synoptic-level datasets on the relevant oceanographic variables. The advent of satellite remote sensing that can measure oceanographic variables at high spatial and temporal resolution has helped to address this challenge. Prior studies have communicated the puzzling dominance of carnivores (fish groups) in North East Arabian Sea (NEAS) whereas planktivores appear to thrive in South East Arabian Sea (SEAS). The study attempts to address this conundrum by taking cues from the influence of oceanographic forcing upon seasonal trends in catch composition using remotely-sensed oceanographic variables and mean standardized catch. The anoxic conditions associated with intense seasonal upwelling in SEAS waters leads to the reduction in the vertical extent of demersal carnivore habitats. The demersal habitats in NEAS waters have a higher likelihood of entraining oxygen rich (>0.5 ml/L) water column when compared with its southern counterpart especially from August to November. Moreover, NEAS waters cater to the nutritional requirements of juvenile demersal carnivore population as it supports primary production both during summer and winter monsoon months. The perpetual presence of chlorophyll biomass allows for the persistence of a prey base that maximizes the likelihood of demersal adult population being well-fed. The poleward directed West India Coastal Current facilitates the passive drift of juveniles towards productive and oxygen rich habitats in NEAS waters. For demersal/pelagic carnivores that undergo recruitment over a long span of time (> 6 months), NEAS waters provide the best spawning ground capable of meeting their long-term nutritional demands. Pelagic planktivores thrive in SEAS, where seasonal upwelling supported primary production remains the norm, owing to their relatively short recruitment span (< 4 months). Unlike SEAS, NEAS waters are found to provide suitable environment geared towards the successful larval recruitment, sustenance and survival of the demersal carnivore group. This could act as a forcing function in driving the annual catch composition of landing data registered in NEAS waters toward carnivore spectrum.

Keywords : Chlorophyll, Upwelling, Monsoon, Remote sensing, Catch composition, Planktivore, Carnivore, Oceanography

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1 Introduction

Understanding the relationship between oceanographic forcing and its impact on fisheries is essential in accurately gauging the effects of climate change upon marine resources of interest. However, this link has remained largely elusive given the lack of synoptic-level datasets on the oceanographic variables that differentiate diverse ocean sites from each other. Satellite remote sensing has played a pivotal role in addressing this data gap by offering the opportunity to measure and monitor multiple oceanographic variables systematically at desired resolutions (George, 2014). With the advent of remote sensing capabilities, seasonal changes in physical forcing and optical responses of coastal waters can easily be monitored (Ikeda, 1995). For example, the South East Arabian Sea reportedly exhibits a strong seasonality in remote sensing reflectance compared with its North East counterpart (Monolisha *et al.,* 2017). Contrary to this observation, conventional wisdom dictates that strong seasonality in environmental variables is persistent in latitudes outside of the Tropical belt (Hartmann, 1994). Seasonal changes in physical forcing influence the biological behavior (spawning, feeding) of fish. Survival of fish larvae will be enhanced if the spawning coincides with the onset of better food conditions in close proximity both temporally and spatially (Platt *et al*., 2003). Fishes also exhibit a natural tendency to avoid predators and provide their larvae with best possible resources to improve their chances of recruitment to their adult fishery stock. Such adaptations aim at improving the odds of larval/juvenile/adult sustenance and survival by taking advantage of resources (food, oxygenated water column) that are locally available. The availability/accessibility of such resources are often dictated by seasonal oceanographic forcing (upwelling, direction and magnitude of surface currents).

Tropical waters are often characterized by high species diversity (Lugo, 1988). Greater species diversity of the Tropics compared with higher latitudes (Pianka, 1989) is well reflected in the commercial fisheries of the eastern Arabian Sea. India, being one of the most prominent tropical fishing nations contributes about 3.5 million tons of fish annually. Over a coastline 8129 km, consistent regional differences in catch composition are observed. Such differences may arise from the influence of multiple forcing factors of physical (upwelling, reversal of surface currents, likelihood of shelf water - nutrient enrichment due to tides), chemical (concentration of dissolved oxygen), geological (nature of continental shelf), biological (primary production, spawning adaptations of fish groups) and anthropological (commercial interest) origin. Madhupratap *et al*., 2001 have communicated the puzzling dominance of carnivores (fish groups) in North East Arabian Sea (NEAS) whereas planktivores appear to thrive in South East Arabian Sea (SEAS). The driving factors responsible for this observed regional difference in catch composition across 15^0N latitude have not been investigated hitherto.

We hypothesize that oceanographic forcing has a strong influence in dictating the seasonal trends in catch composition and can even act as a forcing function in introducing the skewness in catch composition towards carnivore spectrum to the North of 15^0N latitude along the eastern Arabian Sea. In order to test this hypothesis, the study focuses upon investigating the seasonal influence of oceanographic forcing (upwelling, surface currents, likelihood of shelf water - nutrient enrichment due to tides) within the context of spawning adaptations of fish groups of interest

(Section 2.2.2.2). In order to take cues from the influence of oceanographic forcing upon seasonal trends in catch composition, remotely-sensed oceanographic variables and mean standardized catch (a proxy to represent the abundance of a given marine resource of interest) were employed.

2 Materials and Methods

2.1 Study area

The spatial domain (Figure 1) of this study extends from 8^0N to 24^0N and 65^0E to 78^0E covering the entire eastern Arabian Sea. The study site is divided into two sub-domains across the 15^0N latitude, namely the zone that falls north of the 15^0N latitude, referred to as the North East Arabian Sea (NEAS) and the zone that is located south of 15^0N latitude called the South East Arabian Sea (SEAS). For this study, we focus on the coastal waters defined as waters inside 200 m isobaths

FIGURE CAPTIONS

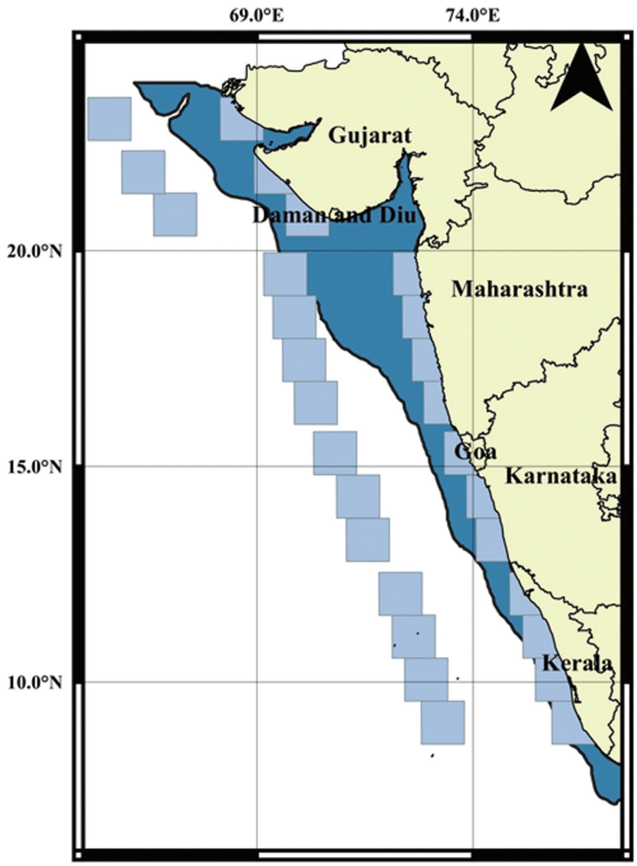

Fig. 1. Study region covering the eastern Arabian Sea. The region (shaded in dark-blue) is enclosed by the coastline on the East and 200 m isobath on the West. The squared-boxes indicate the off-shore and coastal stations considered for deriving Local Temperature Anomaly.

(Figure 1). The marine fish-landing data at monthly intervals for individual States (covering each major marine resource of interest) are mostly derived from the intense fishing that occurs within the Indian Exclusive Economic Zone (EEZ) which extends up to 200 nautical miles from the coast. The 200 m isobath was assigned to ensure adequate spatial overlap between EEZ and highly productive coastal waters (King, 2013) that are likely to serve as spawning sites (for adult fish stock) as well as feeding grounds (for fish larvae, juveniles and adults).The States of Kerala, Karnataka and Goa share their coastline with SEAS whereas Maharashtra and Gujarat coasts lie adjacent to NEAS.

2.2 Datasets used

2.2.1 Physical Datasets

2.2.1.1 Sea-surface wind

The QuikSCAT Level-3 surface wind speed mapped dataset from 2000 to 2009 (NASA, 2012), were obtained at 1°x1° spatial resolution and monthly resolution from the NASA website http:// dx.doi.org/ 10.5067/QSSWS-CMIP1.

2.2.1.2 Sea-surface temperature

The sea surface temperature data, from 2007 to 2016, were derived from NOAA - OI (National Oceanic and Atmospheric Administration - Optimum Interpolation) High Resolution Blended Analysis of daily SST, Version 2 dataset (Reynolds *et al*., 2007) with a spatial sampling of 0.25° available at https://www.esrl.noaa. gov/psd/data/gridded/ data.noaa.oisst.v2.highres.html.

2.2.1.3 Sea-surface height anomaly

The monthly sea surface height anomaly (CMEMS, 2016), having a spatial resolution of 0.25° was derived from Level 4 Global Ocean Gridded Maps REP (Reprocessed) SLA (Sea-level anomaly) from 1993 to 2009 available athttp://marine.copernicus.eu/services-portfolio/access-to-products/ ?option=com_csw&view=details& product id=SEALEVEL_GLO_PHY_L4_REP_OBSERVATIONS_008_047.

2.2.1.4 Sea-surface currents

The near sea surface current estimates from 1993 to 2009 were obtained from Level-4 OSCAR (Ocean Surface Current Analysis Real-time) OC (Ocean current) third degree resolution (0.33° spatial resolution) Version 1 dataset (Bonjean and Lagerloef, 2009) at 5-day temporal sampling. The dataset can be accessed from https://podaac.jpl.nasa.gov/ dataset/OSCAR_L4_OC_third-deg.

2.2.1.5 Vertical Salinity profile and surface density

The vertical salinity profile and surface density was derived from North Indian Ocean Atlas developed for the Indian Exclusive Economic Zone (Chatterjee *et al*., 2012) restricted to a depth of 1500 m. The dataset can be accessed at http://www.nio.org/index/option/com_nomenu/ task/ show/tid/ 2/sid/18/id/229.

2.2.1.6 Bathymetry

The bathymetry dataset was derived from ETOPO1 1 Arc-Minute Global Relief Model dataset at 1 arc-minute spatial resolution (Amante and Eakins 2009). The dataset is available at http:// dx.doi.org/10.7289 /V5C8276M.

2.2.1.7 Tidal amplitude

The tidal elevation time-series data for specific stations across 15^0N latitude namely (Kandla (23^0E, 70.23^0N), Bhavnagar (21.8^0E, 72.15^0N), Mumbai (18.91^0E, 72.83^0N), Mangalore (12.85^0E, 72.83^0N), Beypore (11.16^0E, 75.8^0N) and Cochin (9.96^0E, 76.25^0N) using Tide and Currents Prediction Tool (Flater, 1998) available at http://tides.mobilegeographics.com.

2.2.1.8 Optical classes based on Remote Sensing Reflectance

The dataset containing eight optical classes associated with eastern Arabian Sea were derived from log transformed normalized remote sensing reflectance dataset (Version 2, accessible at ESA CCI Ocean Color website at http://www.esa-oceancolour-cci.org.) for six specific wavelengths (412 nm, 443 nm, 490 nm, 510 nm, 555 nm and 670 nm) across 1998-2013 period by employing fuzzy C mean algorithm (Monolisha *et al.,* 2017).

2.2.2 Biological Datasets

2.2.2.1 Sea-surface chlorophyll

The sea-surface chlorophyll-a concentration for the study region was derived from the OC-CCI (Ocean Color Climate Change Initiative) Version 3, Level 3 Mapped data of chlorophyll concentration (OC-CCI, 2015) at 4 km spatial sampling and monthly temporal resolution from 1998 to 2015. The dataset is accessible at ESA CCI Ocean Color website at http://www.esa-oceancolour-cci.org.

2.2.2.2 Fisheries data

The marine fish species considered for the study (Table A, Supplementary Material) were broadly categorized into pelagic/demersal and planktivore/carnivore groups based on the vertical extent of habitat and diet preferences of adult fish. Adult fish having vertical habitats below 30 m of depth have been assigned under demersal category. The major marine resources of interest considered for the present study include prawns, pelagic planktivores such as anchovies, mackerel, sardines along with demersal carnivores such as pomfrets, perches and croakers. It is to be noted here that we do not treat the these groups to be mutually exclusive as some species can be both planktivore and carnivore whereas most fish species spent their early stages (such as egg, larvae, juvenile) as pelagic entities mostly dependent upon plankton to meet their metabolic requirements. The diet of the adult members of the species categorized as planktivores (Table A, Supplementary Material) mostly comprise of phytoplankton and zooplankton. Apart from plankton (primarily zooplankton), the diet of adult members in species that were labeled as carnivores (Table A, Supplementary Material) also include fish egg/larvae, juveniles and crustaceans. The landing data used for the study pertain to the marine capture fisheries and the list of fishing gears associated with the same is also provided (Table B, Supplementary Material). The marine fish landing dataset for each marine resource of interest coupled with the fishing effort (in terms of the number of units under operation) associated with individual gears were obtained for each State at monthly temporal resolution from Central Marine Fisheries Research Institute database (CMFRI, 2016).

2.3 Methodology used

2.3.1 Upwelling Index

The local temperature anomaly (LTA), a coastal upwelling index, was derived from daily sea surface temperature climatology using Equation (1) by adopting the approach of Wooster *et al*., (1976), Naidu *et al*., (1999), Prell and Streeter (1982), Smitha *et al*., (2008) and Shah *et al*., (2015) following the justification that the key signature of upwelling-dominated regions is based on temperature difference between regions within the same latitudinal belt (Smitha *et al*., 2008; Jayaram *et al*., 2010). The LTA was estimated at the sea surface with a temporal resolution of one day. Upwelling is indicated by positive LTA values.

$$LTA = T_{\text{open ocean}} - T_{\text{coastal waters}} \qquad \text{Equation 1}$$

where $T_{\text{open ocean}}$ represents sea surface temperature associated with an off-shore station at a distance of 3^0 with respect to that recorded at a coastal station (denoted using $T_{\text{coastal waters}}$) within the same latitudinal belt. LTA serves as a proxy to represent oceanographic forcing.

2.3.2 Standardization of marine fish landing data

The marine fish-landing data contains mixed signals underlining the roles played by a myriad of factors (including fishing effort, fishing gear, expertise of the fishermen) and therefore can be considered as a highly biased indicator of abundance for a marine resource of interest. In an attempt to minimize the bias in marine fish landing data due to effort, Catch per Unit Effort was computed using both landing data and effort for each marine resource across multiple fishing gears. The CPUE's were standardized using Multi-Gear Mean Standardization (MGMS) to obtain a dimensionless entity namely Mean Standardized Catch (MSC) which enables us to combine data across multiple gears (Gibson-Reinemer *et al*., 2016). For a given State, marine resource and sampling time, the standardized CPUE data were combined by adding up the Mean Standardized Catch from individual fishing gears (Hinch *et al*., 1991, Jackson and Harvey, 1997). The Mean Standardized Catch (MSC) serves as a proxy to represent the abundance of a given marine resource of interest.

2.3.3 Relevance of Datasets Employed

Climatology of variables such as sea surface wind, sea surface height anomaly, sea surface current sea surface chlorophyll and mean standardized catch were prepared by averaging the dataset of individual month across multiple years. The daily climatology of sea surface temperature was used to derive Local Temperature Anomaly. Sea surface wind climatology was used to identify the seasonality in wind magnitude and direction since it acts as an essential forcing function for the initiation and termination of wind-driven upwelling along the eastern Arabian Sea. Local Temperature Anomaly (an upwelling index based on zonal gradient in sea surface temperature across a single latitudinal belt), derived from daily SST climatology targeted the identification of terminal phase (at daily level) of seasonal upwelling within Indian Exclusive Economic Zone when the coastal water column in its entirety is more likely to entertain anoxic conditions. In order to compare the spread and intensity of upwelling in NEAS and SEAS waters, sea surface height anomaly was employed as a useful proxy. The magnitude and direction of sea surface currents was used to gauge the likelihood

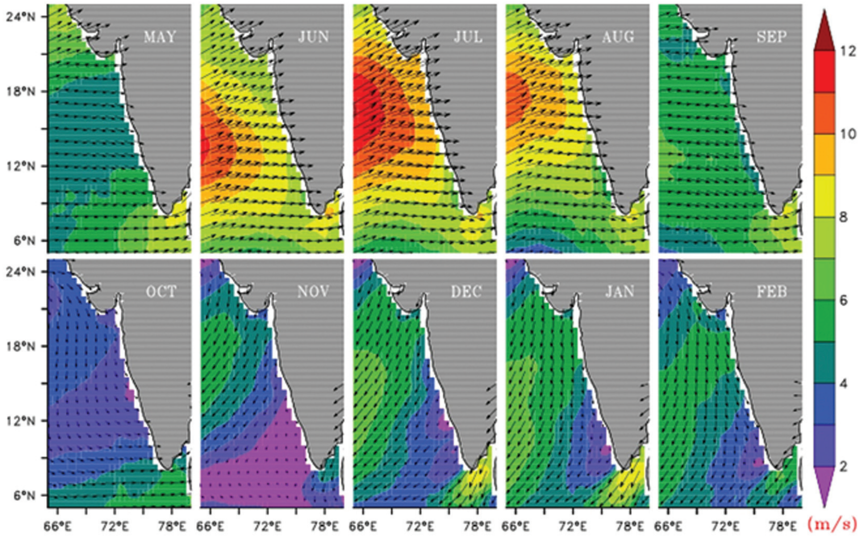

Fig. 2. Climatology of surface wind across eastern Arabian Sea. Panels correspond to months as follows: (A) May, (B) June, (C)July, (D) August, (E)September, (F)October, (G)November, (H)December, (I)January and (J)February.

of fish eggs/larvae transport due to horizontal advection during summer/winter monsoon months. Climatology of vertical salinity profile was used to gain insight with respect to the monthly progression of vertical excursion of sub-surface water during upwelling along the eastern Arabian Sea. The nature of the continental shelf within the Indian Exclusive Economic Zone (EEZ) was characterized using ETOPO 1 bathymetry dataset. Tidal amplitude dataset was used to qualitatively gauge the likelihood of nutrient off-load associated with tidal current amplification (which could potentially enrich the shelf region with nutrients) for NEAS and SEAS waters. The sea surface chlorophyll- a climatology was used to study the persistent and seasonal nature of surface chlorophyll along with the regional differences in its concentration observed across 15^0N latitude. The seasonality of optical classes in NEAS and SEAS waters was investigated using dataset containing eight optical classes derived from remote sensing reflectance (Monolisha *et al.,* 2017).

We speculate that unlike SEAS, NEAS waters provide suitable environment geared towards the successful larval recruitment, sustenance and survival of the demersal carnivore group. In order to put our hypothesis to test, we investigate the seasonality in oceanographic forcing (upwelling, surface currents) with prime focus upon August-November period (when anoxic conditions due to upwelling is known to persist along the eastern Arabian Sea at least up to 15^0N latitude and trawl ban remains lifted) in an attempt to detect its influence in the variation of mean standardized catch for pelagic/ demersal planktivore/carnivore fish groups in NEAS as well as SEAS waters that could potentially explain the seasonality and nature of catch composition along the eastern Arabian Sea.

3 Results

The key findings with respect to oceanographic forcing, namely; Upwelling, Sea surface currents, Role of tides in shelf water-nutrient enrichment are provided in this section along with an overview of the spawning adaptations of fish groups aimed at enhancement of the odds of successful larval recruitment. The section concludes with the impact of upwelling upon catch composition across NEAS and SEAS.

3.1 Oceanographic forcing

3.1.1 Surface current

The climatology for sea surface current is derived from Level-4 OSCAR dataset available at 0.33 degree spatial sampling (Bonjean and Lagerloef, 2009). The sea surface currents are directed equator-ward (Figure 3(B)-(D)) during summer monsoon (especially from June to September) with a velocity range mostly within 0.08 and 0.18 m/s and poleward (Figure 3(H)-(I)) during winter monsoon (from November to February) with a velocity range 0.06 and 0.16 m/s. The magnitude of strength (depending on how well-developed current system is) and direction of sea surface currents can play a dominant role in the horizontal transport during the early stages (egg/larvae) of life-history for a given marine resource when it is mostly at the mercy of surface currents which dictate its horizontal advective transport. Hence, sea surface currents can advect (horizontally) the fish egg/larvae from their respective spawning sites and contribute to the eventual aggregation of fish egg/larvae towards or away from their potential feeding grounds, which in turn could affect their survival and recruitment to adult stock.

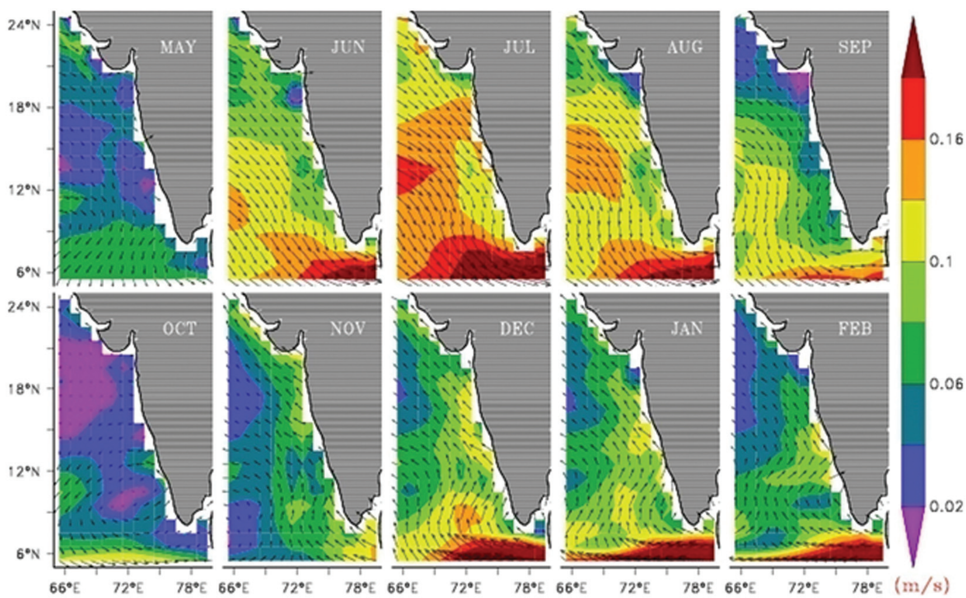

Fig. 3. Climatology of surface currents across eastern Arabian Sea. Panels correspond to months as follows: (A) May, (B) June, (C)July, (D) August, (E)September, (F)October, (G)November, (H)December, (I)January and (J)February

3.1.2 Upwelling/Downwelling in NEAS and SEAS

3.1.2.1 Sea surface wind

The sea surface wind climatology was derived from QuikSCAT Level 3 dataset (NASA, 2012). The eastern Arabian Sea is strongly influenced by the seasonal reversal of monsoon and associated meteorological forcing. During summer monsoon (May-August), winds along this region typically have a velocity range of 5 - 10 m/s along the West coast and are directed from sea towards the land (South West) whereas during winter monsoon (November-January), the wind system reverses its direction and moves from land to sea (North East) with a velocity range of 2 - 6 m/s along the eastern Arabian Sea. Moisture-bearing South West monsoon winds (Figure 2 (C)) exert its influence across the Arabian Sea during July. Dry winds characterizing North East monsoon intensify (Figure 2 (H)) during December over the eastern Arabian Sea. The coastline towards the North of 15^0N latitude lies almost perpendicular to the incoming South West monsoon whereas in SEAS, the winds tend to intersect the land mass at shallower angle (when compared with NEAS region). This difference in angle of incidence can fuel the progressive accentuation (towards lower latitudes) of along shore wind component responsible for wind-driven upwelling that dominates SEAS coastal region during Indian summer monsoon period. The increase in strength of along shore wind component especially towards lower latitudes can contribute to the intense upwelling in SEAS waters (when compared with NEAS) which in turn can increase the likelihood of the entire coastal water column to entrain sub-surface waters deficient in oxygen, thereby rendering such habitats inhospitable especially for demersal populations that thrive below the pelagic zone.

3.1.2.2 Sea surface height anomaly

Climatology for sea surface height anomaly, derived from Level 4 Gridded REP (Reprocessed) SLA (Sea-Level Anomaly) Gridded dataset (CMEMS, 2016) was used as a proxy to gauge and compare the intensity and horizontal spread of upwelling episodes in NEAS and SEAS waters. Lowering of mean sea level during summer monsoon (Figure 4(C)-(E)) indicates upwelling (dominant during July, August and September) whereas elevated sea level during winter monsoon (Figure 4(H)-(J)) indicates downwelling (from December to February) along the eastern Arabian Sea. The sea surface height anomaly consistently exhibits its lowest values (between -3 and -15 cm) during June to September close to the SEAS region. Upwelling signals manifested through negative sea surface height anomaly indicates that it is much stronger and more wide-spread in SEAS especially during August. Such prominent upwelling signals are not observed along the NEAS region. The highest values for sea surface height anomaly (>12 cm) are observed during winter monsoon in SEAS coastal waters whereas such prominent downwelling signals are not observed along the NEAS coastal waters. Consistent negative values for sea surface height anomaly indicate the slow emergence of subsurface water associated with anoxic conditions from the ocean depths replacing the surface water transported rapidly offshore under the influence of upwelling, which could render SEAS waters less conducive for demersal population to thrive. Likewise, persistent positive sea surface height anomaly corresponds to the subduction of surface water into the ocean depths and eventual replacement of anoxic, nutrient rich sub-surface water with oxygen-rich, yet nutrient deficient surface water.

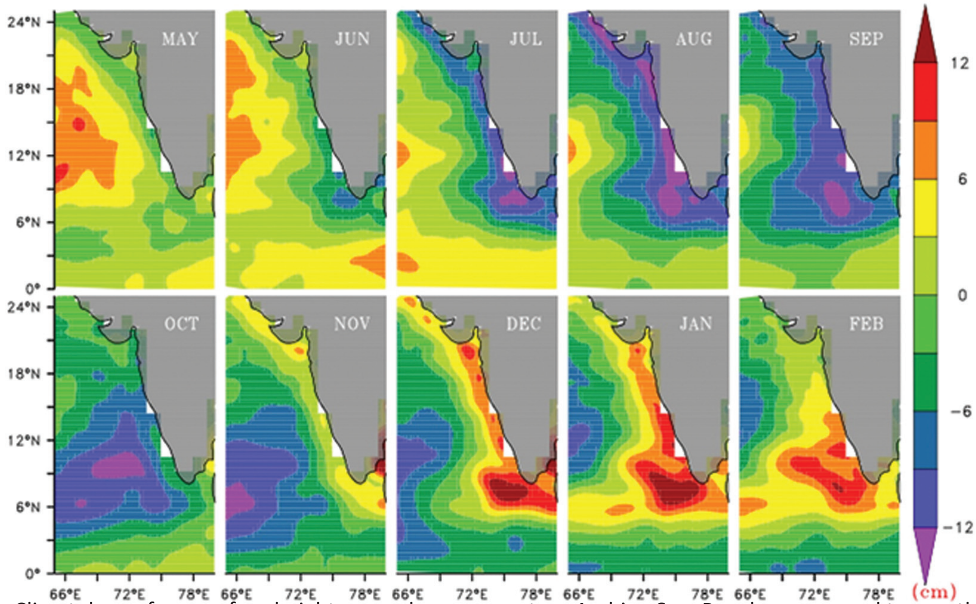

Fig. 4. Climatology of sea surface height anomaly across eastern Arabian Sea. Panels correspond to months as follows: (A) May, (B) June, (C) July, (D) August, (E) September, (F) October, (G) November, (H) December, (I) January and (J) February

3.1.2.3 Vertical excursion of upwelled water

Climatology for vertical salinity profile was obtained from North Indian Ocean Atlas derived by Chatterjee *et al*.,(2012). Upwelling is characterized by the emergence of dense, cold nutrient rich waters from ocean depths to the surface. Along the vertical dimension, such a phenomenon could easily be detected by upward tilt of isopleths whereas the subduction of surface water to the greater ocean depths is manifested by downward tilting isopleths during downwelling.

From Figure 5 panels (C)-(F), it is quite evident that in SEAS during upwelling, the upward tilt of the isopycnals extends from the open ocean to the coastline (66^{0}E to 75^{0}E) where the subsurface water reaches the surface, especially during August and September. This implies that in SEAS, the entire water column adjacent to the coastline has a greater likelihood of entraining nutrient rich waters. This could also indicate that anoxic conditions in coastal water column, a common spawning site for marine resources, could become an established norm in SEAS waters especially towards August – November. Such anoxic conditions (all the way to the surface) when sustained over a span of few months could hamper the survival of marine fish egg/larvae apart from adversely affecting the demersal dwellers whose vertical habitat extent share a larger overlap with anoxic conditions that set in with upwelling.

Downwelling in SEAS (Rao *et al*., 2009) operates during non-upwelling months (November-February) when, in the absence of upwelling-favorable winds, the surface water gets subducted to the ocean depths as highlighted by downward-tilting isopycnals in Figure 5 (H)-(K) and the water-column (closer to the coastline) slowly replenishes its oxygen concentration.

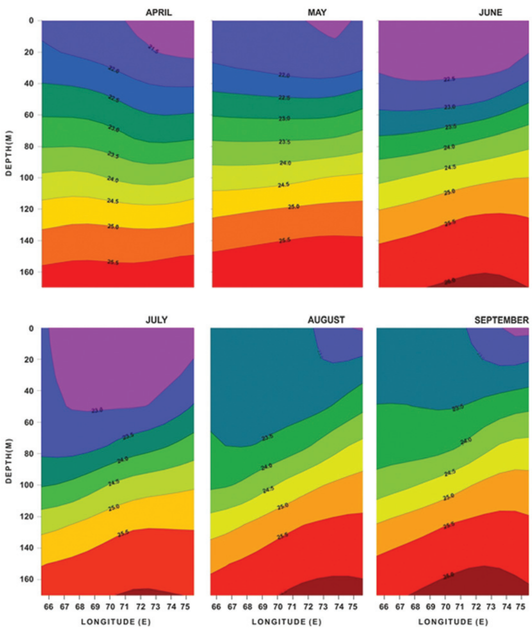

Fig. 5. Isopycnals across eastern Arabian Sea along 8.50N latitude during pre-summer monsoon and South West monsoon period. Panels correspond to months as follows: (A)April, (B)May, (C)June, (D)July, (E)August, (F)September

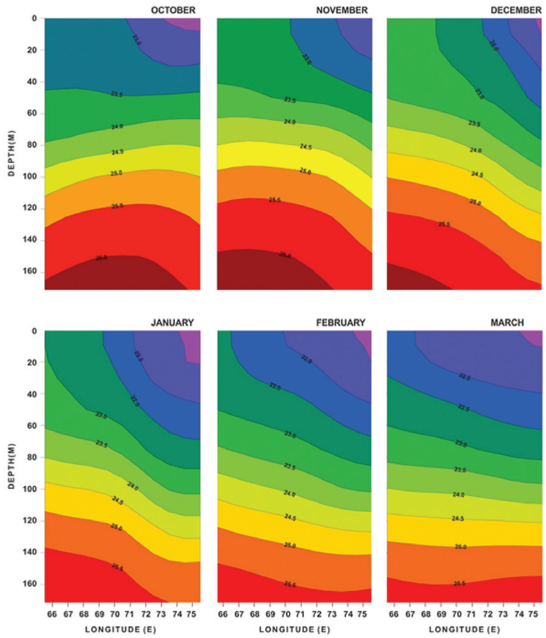

Fig. 5. Isopycnals across eastern Arabian Sea along 8.50N latitude during post South West monsoon and winter monsoon period. Panels correspond to months as follows: (G)October, (H)November, (I)December, (J)January, (K)February and (L) March.

3.1.2.4 Surface density

The surface density was derived from North Indian Ocean Atlas developed by Chatterjee *et al*., (2012). The NEAS region is characterized by the presence of denser water (Figure 6) throughout the year when compared with its SEAS counterpart. The surface density difference between NEAS and SEAS is observed to be minimum during upwelling months (June - September). This could be attributed to the strong upwelling in SEAS which in turn results in the vertical intrusion of dense water from the ocean depth to the sea surface. Since upwelling signals are not as strong in NEAS (when compared with SEAS), the duration of increase in surface density values remains short (June -August), whereas the higher surface density values in SEAS is sustained for longer (April - September) during upwelling months.

For non-upwelling months (November-February), the difference in surface density values between NEAS and SEAS waters is accentuated. This could be attributed to two factors namely:

1) The influx of low-salinity water from Bay of Bengal into eastern Arabian Sea by Winter Monsoon Current (WMC) which bifurcates close to Lakshadweep High and flows as West India Coastal Current along the West coast of India (Wyrtki, 1971; Bruce *et al*., 1994; Han, 1999; Shenoi *et al*., 1999; Shankar and Shetye, 1999; Han and McCreary 2001; Han *et al,* 2001; Howden and Murtugudde, 2001; Shankar *et al*., 2002).

2) Intense downwelling in SEAS (due to Kelvin wave as reported by Rao *et al.,* 2009) can result in the subduction of surface water which in turn gradually replaces the nutrient-rich waters that had flooded the shelf region during upwelling

Subduction of high salinity surface water during winter monsoon in the northern Arabian Sea also contributes to the high surface density values observed in NEAS adjacent to the mixed layer (Morrison, 1997; Schott and Fischer, 2000). Latitudes, particularly 16^0N and 20^0N (Figure 6) consistently register high sigma-t values (>22.4 kg/m^3) in comparison coastal stations (8^0N and 11^0N) in SEAS thereby suggesting that denser surface waters characterize the coastal waters to the North of 15^0N latitude.

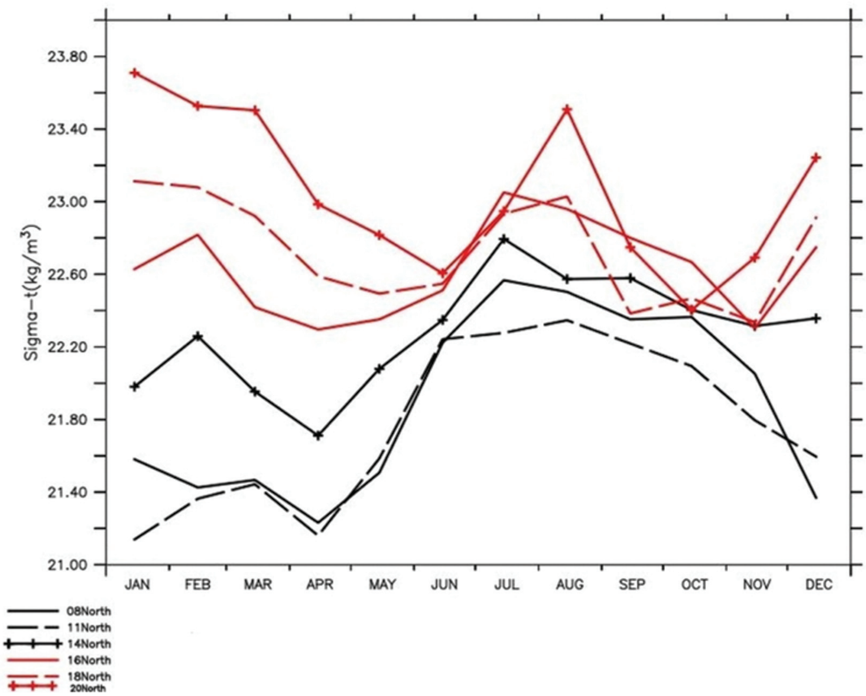

Fig 6. Seasonality of sea surface water density across multiple latitudes (80N, 110N, 140N, 160N, 180N and 200N latitude). Red and black color denotes stations located in NEAS and SEAS respectively.

The surface density acts as a critical factor in determining the vertical positioning of marine fish egg (Sundby and Kristiansen, 2015) since adult marine fishes can alter the buoyancy of the eggs (May, 1974) in response to the environmental density variations to optimize the chance that their eggs/larvae remain adjacent to surface coastal waters that are more likely to be productive (with lower predation pressure) enough to sustain their metabolic requirements during the critical phase of larval development in order to facilitate higher likelihood of recruitment of the juveniles to adult stock.

3.1.2.5 Sea surface chlorophyll

The sea surface chlorophyll dataset was obtained from OC-CCI (Ocean Color Climate Change Initiative) chlorophyll-a concentration (Version 3) dataset (OC-CC1, 2015). High values of chlorophyll biomass (Figure 8 (C)-(E)) are observed along the eastern Arabian Sea during peak (when monsoon winds attain their maximum magnitude) months (June - September) of summer monsoon owing to the intense upwelling characterizing the eastern Arabian Sea coast. However, despite the absence of upwelling-favorable winds over NEAS waters during winter monsoon, we observe high chlorophyll biomass values particularly in northern Arabian Sea (Figure 8 (G)-(J)) due to the influx of iron-rich aerosols transported by the dry North East monsoon winds from Indian sub-continental desert regions (Kumar., 2010) and the winter convective mixing (Madhupratap *et al*., 1996; Kumar and Prasad, 1996) in coastal waters.

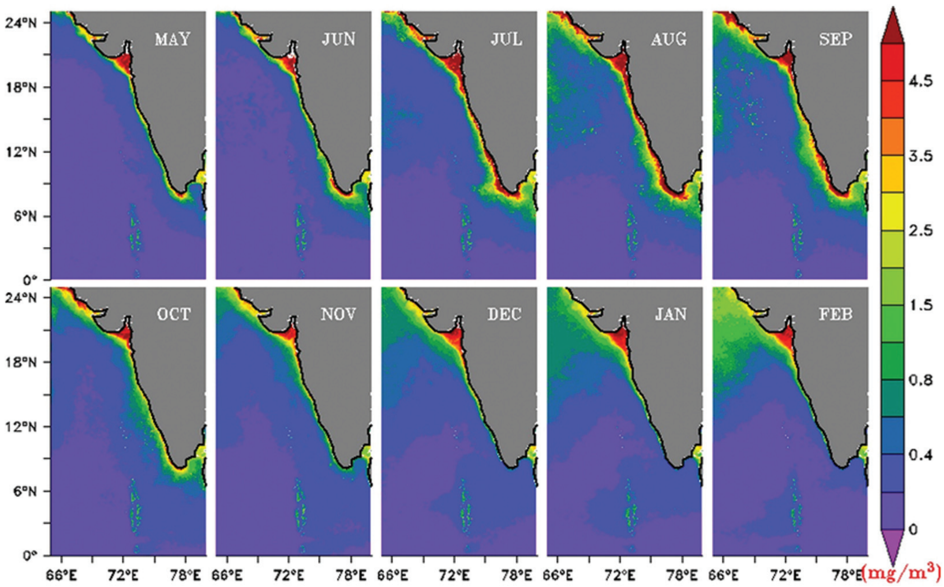

Fig. 8. Climatology of sea-surface chlorophyll for eastern Arabian Sea. Panels correspond to the months as follows: (A) May, (B) June, (C)July, (D) August, (E)September, (F)October, (G)November, (H)December, (I)January and (J)February

The peak (approximately 4.75 mg/m^3 for 9^{0}N latitude) in surface chlorophyll-a values recorded in SEAS waters (Figure 9) spans across all the summer monsoon months (May - September) whereas for NEAS waters, the spike (approximately 7.5 mg/m^3 for 21^{0}N latitude) in surface chlorophyll-a lasts for a shorter duration (June - August). Such an observation indicates that SEAS holds more favorable conditions for phytoplankton for a longer duration than NEAS especially during upwelling months. However, it should also be noted that NEAS waters (21^{0}N latitude) consistently registers a higher surface chlorophyll value with respect to SEAS (9^{0}N latitude) throughout the course of an entire year. This difference in surface chlorophyll- a between NEAS and SEAS waters could be attributed to the crucial role played by winter convective mixing along with nutrient-enrichment of

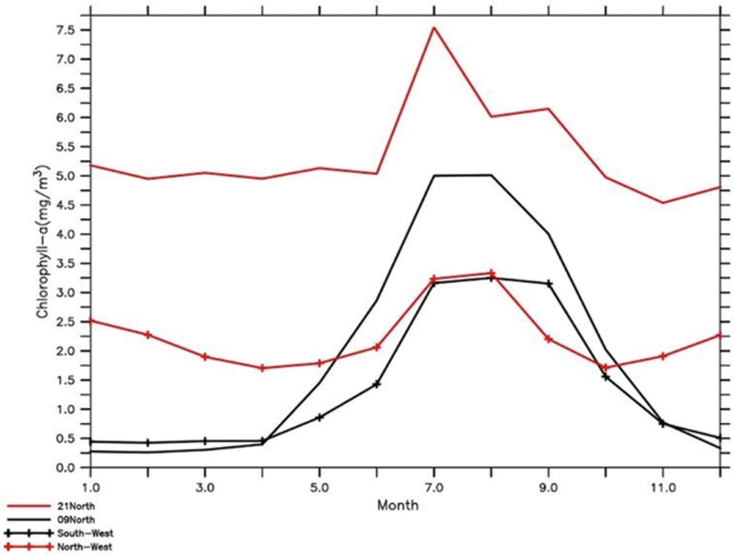

Fig. 9. Seasonality of chlorophyll across multiple latitudes (90N and 210N latitude) in eastern Arabian Sea. . Red and black color denotes stations located in NEAS and SEAS respectively. X-axis labels correspond to months as follows: 1)January, 2)February, 3)March, 4)April, 5)May, 6)June, 7)July, 8)August, 9)September, 10)October, 11)November and 12)December

NEAS surface waters by deposition of iron-rich aerosols associated with dry North East monsoon winds. In the absence of upwelling-favorable winds during winter monsoon, SEAS surface waters remain nutrient-poor and are not capable of maintaining high chlorophyll concentrations (as observed during upwelling months). In NEAS, during non-upwelling months, winter convective mixing and fertilization of surface waters under the influence of iron-rich aerosols collectively sustain higher surface chlorophyll-a values (1.75 - 2.5 mg/m^3) when compared with SEAS waters which remain nutrient-poor during the same period. Therefore, NEAS is capable of ensuring the critical nutrient-supply required for phytoplankton to flourish during upwelling (May - October) as well as non-upwelling months (November - February). Here we speculate that the primary production observed though out the year in NEAS waters could potentially act as a strong foundation that could consistently sustain planktivore group which in turn could serve as prey base to support a thriving carnivore community.

3.1.3 Tidal current amplification

The tidal amplitude data was obtained using an online tool used for prediction of tidal amplitudes and currents (Flater, 1998). Apart from upwelling, significant nutrient off-load has also been attributed to tidal currents. The occurrence of viable coral reefs associated with waters characterized by low nutrient content has been attributed to the nutrient off-load associated with tidal currents (Thompson and Golding, 1981). Presence of island chains separating continental shelf from open sea can further accentuate the net transfer of nutrient load to the continental shelf waters through tidal current amplification (Maxwell 1968) owing to the limited tidal wave access. Narrow channels between the islands further strengthen the tidal currents thereby initiating intense mixing on the continental shelf. Periodic nutrient off-load to the continental shelf region by tidal floods can cause substantial nutrient enrichment of surface waters even in the absence of wind-driven upwelling. However, the nutrient off-load associated with such mechanisms might relatively be less in comparison with that of upwelling, yet sufficient enough in lending a supporting role (in addition to surface fertilization of coastal waters by iron-rich aerosols) to the essential nutrient supply required for the sustenance of primary production in NEAS coastal waters, especially during winter monsoon months.

Moreover, the continental shelf area is wider in NEAS in comparison with SEAS. The tidal amplitudes exhibit a strong variation across 15^0N latitude. The maximum values for tidal elevation for the sites located towards North of 15^0N latitude (NEAS) namely Kandla, Bhavnagar and Bombay (Figure 7) vary mostly between 4 – 10 m whereas for sites situated to the South of 15^0N latitude (SEAS) namely Cochin, Mangalore and Beypore, the maximum values for tidal amplitude vary between 1 - 2 m. The NEAS waters with high tidal amplitudes, wide continental shelf characterized by the presence of islands (especially Gujarat coastline) has higher likelihood of surface water nutrient-enrichment through tidal current amplification in comparison with SEAS waters characterized by low tidal amplitudes and narrow shelf. Here we speculate that such mechanisms that enrich shelf waters can contribute to support primary production in the absence of upwelling-favorable winds (during October - February) especially in NEAS waters.

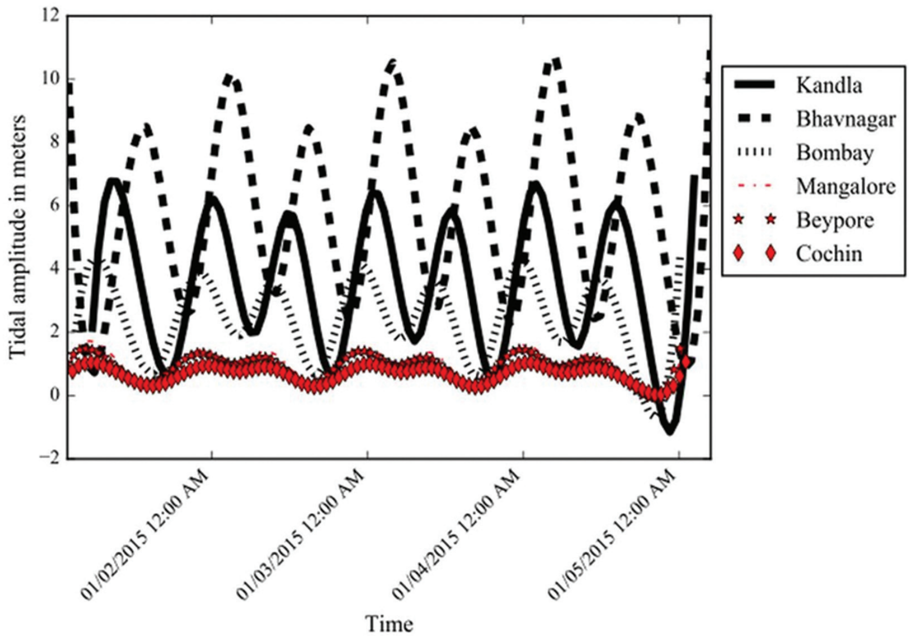

Fig. 7. Variation of tidal amplitude across the eastern Arabian Sea. Tidal stations located to the North and South of 150N latitude are highlighted using black and red color respectively.

3.2 Optical Classes derived from Remote Sensing Reflectance

The dataset containing eight optical classes for eastern Arabian coastal waters was derived from OC-CCI (Ocean Color Climate Change Initiative) remote sensing reflectance dataset (Version 2) for 1998-2013 period using fuzzy C mean algorithm (Monolisha *et al.,* 2017). A strong seasonality (Figure 10) in the optical classes derived from remote-sensing reflectance was observed for SEAS waters (South of 15^{0}N latitude) whereas no such seasonal signal was detectable from NEAS. This could be attributed to the primary production supported by intense seasonal upwelling during summer monsoon in SEAS waters whereas for NEAS, we observe that the primary production is well supported throughout the year even in the absence of upwelling favorable winds (Figure 8 (F)-(J)).

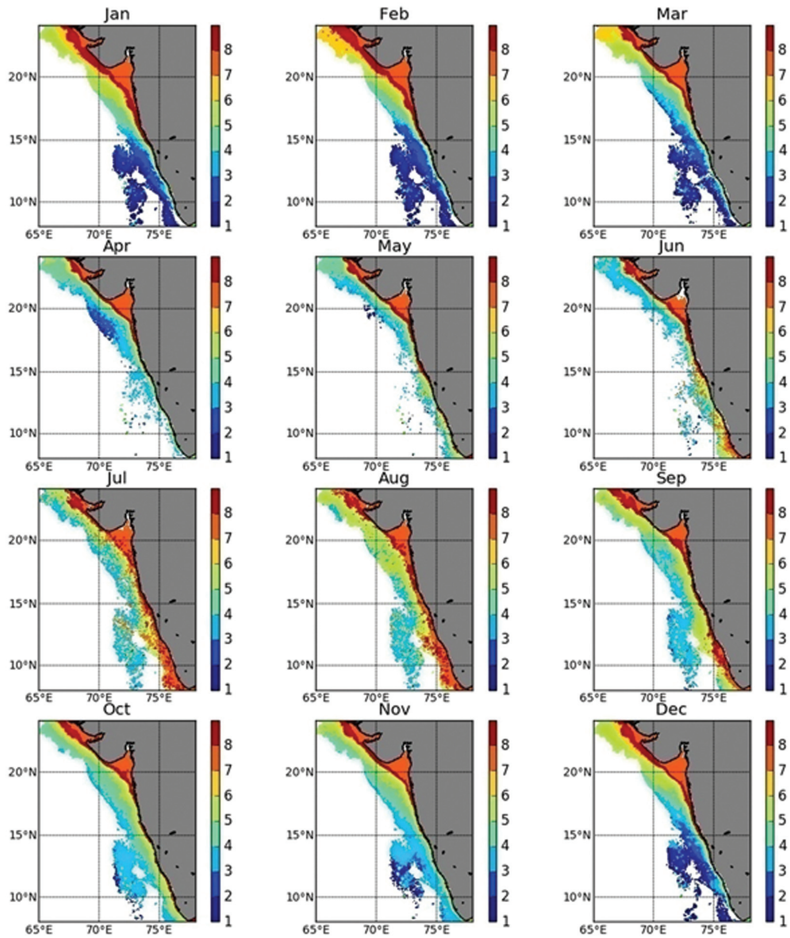

Figure 10. Seasonal variation in optical classes derived from remote sensing reflectance along the entire eastern Arabian Sea. Panels correspond to months as follows: (A)January, (B)February, (C)March, (D)April, (E)May, (F)June, (G)July, (H)August, (I)September, (J)October, (K)November and (L)December

3.3 Spawning behavior and recruitment

The temporal extent of spawning season for key species within each group was compiled from scientific literature. The term breeding has been used interchangeably with spawning although the former involves a chain of events in connection with pre-spawning and spawning phases (Qasim, 1973). Breeding season subsumes the time of peak maturity and spawning period in a population. Likelihood for recruitment of newly produced broods to adult stock is enhanced when spawning overlaps (both spatially and temporally) with favorable (availability of food resources, safety from predators) of newly hatched larvae. The spawning behavior of representative species belonging to the major pelagic planktivore and demersal carnivore groups is highlighted in Table 1. Species representing individual groups were chosen based on their commercial importance. A common thread with respect to spawning behavior that we can note from Table 1 is that spawning period for the pelagic and demersal marine resources overlaps with the summer monsoon months (May - September) which in turn coincides with upwelling along the eastern Arabian Sea. This could be attributed to the fish-larvae favorable conditions (availability of food) that persist in close proximity to the coast throughout the entire Arabian Sea during summer monsoon. Although primary production is a critical factor for successful larval recruitment, it is not a sufficient condition (Bakun *et al*., 1998). In an effort to increase the likelihood of successful recruitment of larvae to adult stock, the spawning fish population tend to minimize larval mortality (due to food scarcity, predation pressure, anoxic conditions) by selectively breeding in sites or adapting their egg buoyancy in response to environmental fluctuations where larvae-favorable conditions (availability of food, minimum predation pressure and oxygen rich environment) tend to persist (for example adjacent to the coastal surface waters) at least until they transition from the critical larval phase when their survival is most susceptible to availability of food resources in the near vicinity (both spatially and temporally), accessibility to oxygen-rich environment and predation pressure.

Table 1. Species-wise spawning season

Group Name	Species name	Breeding season	Cited in
Oil sardine	*Sardinella longiceps*	June - September	Dhulkhed, 1964
Mackerel	*Rastrelliger kanagurta*	June - July	Radhakrishnan, 1962
Anchovies	*Encrasicholina devisi*	July-September, October/ November - June	Luther, 1979
Perches	Nemipterus japonicus	June - August	Murthy et al., 1992
Croakers	*Otolithes ruber*	July - October	Devadoss, 1969
Pomfrets	*Pampus argenteus*	April - June	Gopalan, 1967

3.4 Influence of oceanographic forcing in fish catch seasonality

The monthly climatology for individual marine resource of interest was derived from Mean Standardized Catch for individual States and their seasonality was investigated within the context of coastal upwelling using Local Temperature Anomaly derived from daily sea surface temperature climatology. The prime focus of this analysis revolves around months (highlighted using green color in Figure 11, Figure 12 and Figure 13) that characterize the terminal upwelling phase (August-September) along with early onset of winter monsoon months (October- November) along eastern

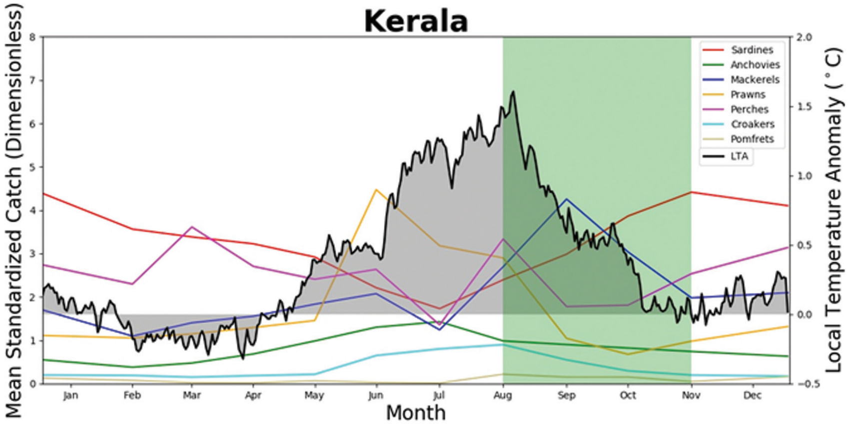

Fig. 11. Monthly Mean Standardized Catch (highlighted by colored solid lines) for the State of Kerala overlaid upon daily Local Temperature Anomaly (coastal upwelling index, highlighted by grey region bordered with solid black line). The region highlighted in green coincide with the terminal phase of upwelling in eastern Arabian Sea along with the onset of winter monsoon season. The Y-axis on left-hand side represents Mean Standardized Catch whereas the one on the right hand side indicate strength of upwelling in degree Celsius. The X-axis correspond to time in months.

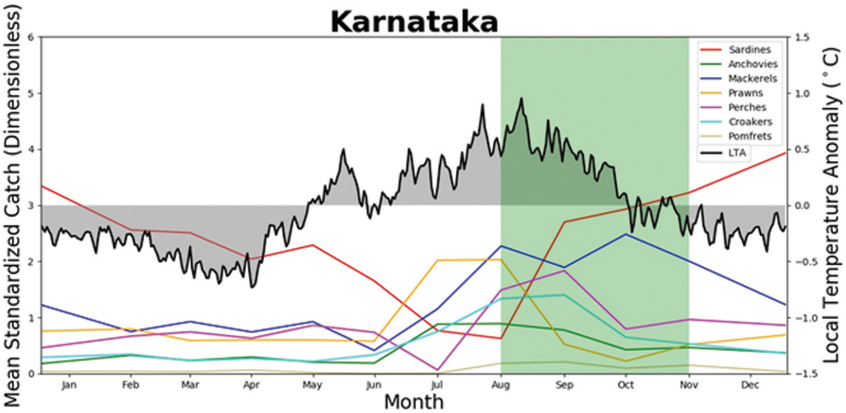

Fig. 12.Monthly Mean Standardized Catch (highlighted by colored solid lines) for the State of Karnataka overlaid upon daily Local Temperature Anomaly (coastal upwelling index, highlighted by grey region bordered with solid black line). The region highlighted in green coincide with the terminal phase of upwelling in eastern Arabian Sea along with the onset of winter monsoon season. The Y-axis on left-hand side represents Mean Standardized Catch whereas the one on the right hand side indicate strength of upwelling in degree Celsius. The X-axis correspond to time in months

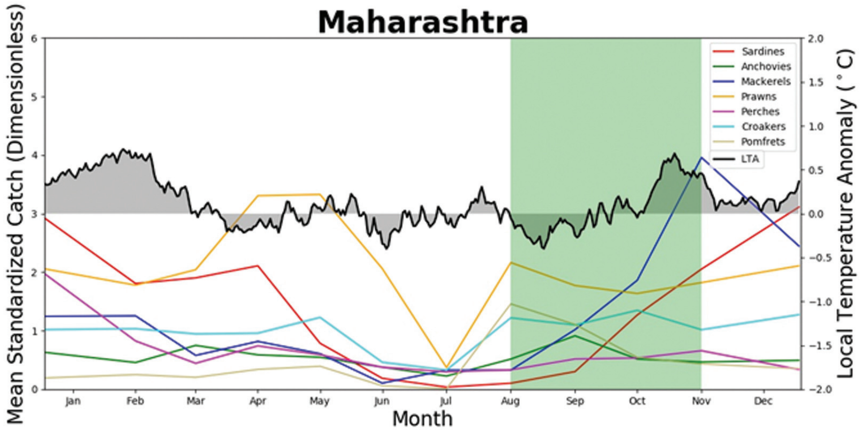

Fig. 13. Monthly Mean Standardized Catch (highlighted by colored solid lines) for the State of Maharashtra overlaid upon daily Local Temperature Anomaly (coastal upwelling index, highlighted by grey region bordered with solid black line). The region highlighted in green coincide with the terminal phase of upwelling in eastern Arabian Sea along with the onset of winter monsoon season. The Y-axis on left-hand side represents Mean Standardized Catch whereas the one on the right hand side indicate strength of upwelling in degree Celsius. The X-axis correspond to time in months.

Arabian Sea since this time frame has the maximum likelihood of entraining anoxic conditions in the entirety of the coastal water column (spanning across pelagic and demersal habitats) along the eastern Arabian Sea (Naqvi *et al.*, 2009). For Kerala and Karnataka, the demersal groups such as prawns, perches and croakers reveal a consistent decreasing trend during August-November period (Figure 11 and Figure 12) whereas pelagic entities (for example sardines) reveal an increasing trend for the same period. It is striking to note that such a strong declining trend was not observed for demersal entities in NEAS waters (Figure 13) whereas an increasing trend (similar to that of Kerala and Karnataka) was observed for pelagic planktivore groups (sardines and mackerels) for the State of Maharashtra. The intrusion of oxygen-deficient subsurface water during upwelling have detrimental impacts in store for demersal carnivores and prawns (Banse, 1959, Naqvi *et al.*, 2009) that inhabit SEAS waters where the likelihood of vertical habitat reduction for such groups due to upwelling is very high with respect to NEAS waters. However, pelagic groups appear to be relatively less affected (when compared with demersal population) in both SEAS and NEAS waters. The upwelling signals being visible at the surface (Figure 13) in NEAS waters only towards October-November appear to suggest delayed overlap of anoxic conditions associated with upwelled waters with demersal habitat beyond 15^0N latitude. The early onset of upwelling signals at the surface level in SEAS waters as revealed by Local Temperature Anomaly also appear to suggest that the demersal habitats in SEAS waters remain anoxic for a longer duration (August-October) when compared with NEAS waters. The upwelled waters, in NEAS, reach a depth of 30 m (Shah *et al.*, 2015) close to November when anoxic conditions tend to subside with the reversal of West India Coastal Current (Naqvi *et al.*, 2009).

4 Discussion

The section synthesizes the key findings of the study by attempting to isolate the underlying oceanographic factors responsible for the observed regional difference in annual catch composition along the eastern Arabian Sea across 15^0N latitude (Madhupratap *et al*., 2001).

4.1 Upwelling in SEAS

In SEAS, the month of May marks the arrival of South West monsoon wind which persists until the end of September. Upwelling in eastern Arabian Sea has been attributed to both remotely-forced baroclinic adjustment and along-shore component of wind stress field accentuated during South West monsoon period (Wyrtki, 1973; Shetye *et al*., 1985; Shetye and Shenoi, 1988; Gopalakrishna *et al*., 2008; Jayaram *et al*., 2010). Geostrophic upward tilt of density contours is initiated during April even before wind-driven upwelling sets in (Longhurst, 2010). The anti-cyclonic gyre conceived by the South West monsoon also lends additional support to the shoreward tilting up of isopleths in Arabian Sea (McCreary *et al.,* 1993). Once the equatorward wind stress field intensifies, Ekman pumping becomes a norm along the eastern Arabian Sea during summer monsoon. It should be noted here that wind stress required to initiate upwelling is relatively less with respect to what higher latitudes demand. During pre-upwelling period, the off-shore component of equatorward flow is weak with nutrient-poor surface waters. Although, the mixed layer remains shallow, subsurface waters with low oxygen content initiates its progress to the shelf. With the onset of Ekman upwelling, nutrient content of surface water increases and an environment with extremely low (< 0.5 ml/L) oxygen concentration is established in the shelf waters beneath the thermocline (Longhurst, 2010). Intense upwelling in SEAS could also dislodge nutrients trapped in mud banks (found exclusively in SEAS) associated with coastal waters contributing to further enrichment. Vertical intrusion of oxygen-deficient subsurface waters onto the shelf region is another norm that exists in eastern Arabian Sea during upwelling (Wooster *et al*.,1967) along with the spread of shoreward tilting up of thermoclines towards higher latitudes (NEAS). Equatorward WICC is also reported to be stronger in SEAS than NEAS (Shankar *et al*., 2002). Therefore, during summer monsoon nutrient-enrichment of surface waters is more intense in SEAS (compared with NEAS waters) as a suite of forcing factors working in unison to bring sub-pycnocline water to the surface.

4.2 Effect of upwelling upon primary production

Assuming that sea surface height anomaly serves as a proxy for intensity of upwelling/ downwelling, we observe that upwelling is stronger and spread across a larger area in SEAS, whereas it is restricted over a smaller area within the NEAS during the summer monsoon period. Similar behavior is observed during winter monsoon period, where downwelling is observed to be less dominant (lower in magnitude and highly localized) for latitudes north of 15^0N. The South West monsoon winds play a pivotal role in initiating the Ekman pumping mechanism which allows the cool nutrient rich waters (Figure 5 (C)–(F)) from the depths to reach closer to the surface. Upwelling is the primary factor responsible for enhanced biological production in the SEAS waters. However, it is interesting to observe that the NEAS is capable of sustaining a higher chlorophyll biomass (close to 7 mg m^{-3}) even during the winter-monsoon period where the wind system reverses its direction (with respect to the summer monsoon period). The progressively (longitude-wise) downward tilting isopycnals (Figure 5(C)-(F)) indicate downwelling along the eastern Arabian Sea suggesting that there might be factors (winter convective mixing, surface fertilization of coastal waters by iron-rich aerosols) other than Ekman pumping responsible for sustaining high chlorophyll biomass in NEAS. Although the North East monsoon winds are not conducive to upwelling along the eastern Arabian Sea, higher chlorophyll biomass values in the NEAS can be attributed to the winter convective mixing (with a net heat loss of approximately 30 Wm^{-2} and freshwater loss of approximately 125 mm per month during winter due to evaporative cooling as reported by Madhupratap *et al.,*(1996)) and the influence of iron-rich aerosols brought by the dry winter monsoon winds (Kumar *et al.,*(2010)) from the sub-continental desert region. The iron rich dust aerosols (observed to increase the Aerosol Optical Thickness from 0.19 to 0.24 during September as reported by Kumar *et al,* (2010)) also tend to fertilize the NEAS waters from the surface thereby enhancing the biological production during winter monsoon period. The tilting up of isopycnals underlines the importance of the strong mixing responsible for entraining nutrients that fuel the seasonal spike in chlorophyll biomass in SEAS.

4.3 Nutrient-enrichment and primary production in NEAS

Weak dry winds (North East directed) dominate over Arabian Sea during winter monsoon (November - February). Downwelling of surface waters near the coast is triggered by the cyclonic circulation (with WICC directed poleward) that persists in the Arabian Sea during this period. Seasonal convective mixing initiated due to winter cooling of NEAS waters was observed to be dominant especially towards North of 18^0N latitude (Banse, 1968; Banse, 1984; Kumar and Prasad, 1996). Enrichment of NEAS surface waters due to the influx of iron-rich aerosols transported by North East monsoon winds from inland desert (Kumar *et al*., 2010) reinforces enrichment of NEAS waters during non-upwelling months. Therefore, NEAS is capable of supporting higher chlorophyll biomass whereas nutrient-poor surface waters in SEAS remains relatively barren during winter monsoon period (Figure 5 (E)-(F)).

Tidal amplitude for latitudes north of 15^0N latitude fluctuates in the range of 6 to 10 m whereas for the SEAS it falls within 1 to 2 m. We speculate that the shallow continental shelf, coupled with higher tidal elevation, facilitate the frequent nutrient-enrichment of shelf waters through the periodic nutrient off-load associated with amplified tidal currents (Thompson and Golding, 1981) in NEAS, which in turn offers additional support (apart from winter convective mixing, surface water fertilization due to iron-rich aerosols) to the sustenance of higher chlorophyll biomass (with respect to SEAS during winter monsoon months) even in the absence of favorable external wind forcing. However, for SEAS, with narrow continental shelf and lower tidal elevation, the odds are against such forms of nutrient enrichment and therefore sustenance of primary production can only become a reality with the support of strong external wind-forcing (such as summer monsoon wind system) that could initiate the vertical crawl of nutrient rich subsurface waters through Ekman pumping.

4.4 Reproductive habitat ecology

The likelihood of successful recruitment of juveniles to adult fish stock improves with the increased overlap of algal bloom across time and space with spawning season and breeding grounds respectively, where their metabolic demands can be met (Platt *et al.,* 2003). Although primary production directly constitutes a critical component for the development and sustenance of coastal pelagic fish population, it is not considered a sufficient condition. The critical processes that work together to address the requirements of juvenile population include enrichment (such as upwelling, mixing), concentration processes (convergence, frontal formation) and processes that support retention (of critical resources such as food) or passive drift towards favorable habitats (Bakun *et al*., 1998). Enrichment processes serve the metabolic requirements of juvenile populations. Concentration processes ensure that the juveniles have access to food resources in their immediate neighborhood thereby providing improved feeding conditions (Bakun, 1996). Passive larval drift stage is common across multiple marine life-forms. Processes that favor drift (towards larvae-friendly habitats) tend to minimize immense wastage of reproductive resources through massive loss of potential recruits in their early life-stages. Adapting the egg buoyancy in response to environmental fluctuations is another strategy adopted by fish groups to ensure that their eggs remain suspended adjacent to surface waters characterized by availability/accessibility to better food conditions (when compared with deeper waters). Therefore, fish populations tend to strategically spawn in certain locations at particular seasons to minimize early losses (Parrish, 1981).

4.4.1 Role of surface currents in fish recruitment

The summer and winter monsoon current form a subset of the West India Coastal Current (WICC) system characterizing near-surface circulation (limited to uppermost few hundred meters) of seasonally reversing nature (Shetye, 1998). Among many pioneering advances (Potemra *et al*., 1991; Yu *et al*., 1991; Shankar *et al.,* 1996; Vinayachandran *et al.,* 1996) aimed at improving the understanding of large-scale seasonal currents in North Indian Ocean, the one that stands out in successfully identifying the driving elements (free and forced long waves set off by the monsoon winds) of WICC is McCreary *et al*., (1993). The first appearance of southward flowing WICC along West coast was reported for the month of March, followed by its peak prominence (with respect to magnitude) during July and the waning phase concludes by October (Cutler and Swallow,1984; Shetye and Shenoi, 1988). The equatorward WICC, which is least prominent off the North West coast, slightly gains strength in the middle (closer to 15^0N latitude) and evolves into a major current system off South West coast of India (Shetye, 1998). However, the poleward-directed WICC, which is better developed than its equator-ward counterpart (Shetye, 1998), becomes dominant current system from December to March (Shankar *et al.,* 2002) and temporally overlaps with the winter monsoon period (Schott and McCreary, 2001). Although the association of life-history of marine resources (especially during the egg/larval stage) with surface current patterns could be labeled as intricate (Sinclair, 1988), in this section, we attempt to elucidate (qualitatively), the role of surface current in egg/larval drift along with its implications for fisheries recruitment. During the initial stages of the lifecycle, the movement of fish larvae is dictated largely by ocean currents. The sea surface current (WICC), directed towards the equator (Figure 3(B)-(D)) during South West monsoon period is responsible for the advection and accumulation of the pelagic eggs/larvae closer to the waters adjacent to the southern States such as Karnataka and Kerala, which serve as the feeding ground for larvae since SEAS waters register a high chlorophyll biomass value during South West monsoon period. NEAS manages to sustain primary production in its coastal waters during winter-monsoon months when SEAS waters remain largely unproductive. The equatorward wing of WICC is observed to be prominent in SEAS domain whereas it is hardly perceptible in NEAS (Shankar *et al.,* 2002). Therefore, we conclude that the eggs of pelagic/demersal fish population, occupying NEAS habitats, whose spawning season overlaps with upwelling months undergo very little horizontal drift (due to equatorward WICC) thereby allowing its juveniles to have close proximity to productive feeding grounds having surface waters with relatively rich oxygen concentration when compared with SEAS waters (since sub-surface waters reach a depth of 30 m in NEAS waters as reported by Shah *et al.*, (2015)), which is critical in ensuring successful recruitment of juveniles to adult fish stock. During North East monsoon period, the sea surface currents (of WICC) are directed poleward along the eastern Arabian Sea (Figure 3(H)-(I)). The demersal eggs/larvae suspended closer to surface drift passively with the surface currents and accumulate in the waters closer to northern Maharashtra and Gujarat which in turn act as the feeding ground for fish larvae as NEAS waters are characterized by high chlorophyll biomass during winter monsoon unlike their south eastern counterpart. During summer monsoon months (when pelagic planktivores usually spawn), the surface currents are directed equator-ward which ensures a similar drift of fish eggs/larvae towards habitats with better feeding conditions. Such strategies developed by fish population aid the survival and recruitment of their respective larvae into adult stock.

4.4.2 Role of density in fish recruitment

NEAS waters registers a higher surface density (with respect to SEAS waters) throughout the course of the entire year and this difference in surface density is accentuated especially during winter monsoon period (Figure 6). This could either be attributed to the influx of low-salinity water by pole-ward flowing West India Coastal Current (owing to the close proximity of SEAS waters to the incoming freshwater transport distributed along the eastern Arabian Sea by WICC) or the intense downwelling (Rao *et al.,* 2009) of surface waters in SEAS which in turn replaces the dense waters that had flooded the shelf during upwelling. Salinity has been reported as a key factor determining the buoyancy in marine fish eggs, which in turn dictates their vertical distribution (in water column) and dispersal under the influence of currents (Sundby and Kristiansen, 2015). In the context of fisheries, buoyancy adaptations have been known to exist as a strategy to improve the odds of survival of fish larvae. Proximity of fish eggs/larvae with respect to surface waters ensures low-level threats from predators with better access to food resources (primary production) that thrive in nutrient-rich surface waters (through upwelling/winter-convective mixing/surface fertilization) in presence of sunlight. Salinity has been reported to have a profound effect upon egg buoyancy as well. Even within the same species (*Bairdiellaicistia*) for Sciaenids, eggs fertilized in less dense water were observed to be more buoyant than the ones found in more saline environment (May, 1974). The more buoyant pelagic eggs naturally rise to the surface in the SEAS water with lower surface density whereas the denser demersal eggs remain suspended within the water column adjacent to the surface in saline NEAS waters. Moreover, the spawning season of most of the species coincides with the summer monsoon period (Table 1). Higher accessibility to food resources closer to spawning grounds ensures sustenance and survival during the critical period of larval development and increases the chances for subsequent recruitment to fish-stock.

4.5 Favorable habitat for demersal resources

For eastern Arabian Sea, the visibility of upwelling signals at the surface (during May and September) is limited up to 16^0N latitude (Shah *et al.,* 2015). During summer monsoon months, the vertical limit observed for upwelled water in NEAS is 10 m whereas sub-pycnocline waters were able to reach the surface in SEAS territory (Shah *et al*., 2015). Since weak upwelling signals (at the surface level) persist in NEAS, vertical excursion of oxygen poor sub-pycnocline waters is limited. Therefore, upwelling in NEAS fails to replace completely the oxygen rich surface waters in the shelf region with oxygen deficient subsurface waters. Although anoxic conditions might prevail in NEAS during summer monsoon, such inhospitable conditions are less extreme and lasts for a shorter span of time when compared with SEAS waters. Therefore, NEAS offers column waters with tolerable oxygen levels (compared with SEAS) for the demersal dwellers to survive especially during upwelling months. Hence, the demersal group (prawns, perches and croakers) are able to thrive in the partially oxygenated water column (close to 30 m depth from the sea surface) associated with NEAS waters along with the pelagic entities (sardines, mackerel) especially during terminal phase of upwelling (August to September) or initial phase of winter monsoon (October to November) as highlighted by Figure 13. The inhibition of surface divergence with the cross-shore driven surface mass transport overpowering the Ekman pumping mechanism in NEAS has been documented as well (Muraleedharan and Kumar, 1996, Shah *et al*., 2015). Since upwelling intensity observed in NEAS is not as strong (with respect to SEAS) at the surface level, the weak off-shore transport associated with the same (coupled with strong cross-shore driven surface mass transport) could contribute in retaining the primary production within its coastal waters. During non-upwelling months (November to February), NEAS waters remain nutrient rich (due to winter convective mixing and nutrient enrichment of surface waters by iron-rich aerosols), thereby providing ideal conditions to sustain primary production (unlike SEAS). Downwelling in NEAS during winter monsoon ensures concentration of primary production within its coastal waters. The poleward directed WICC facilitates the passive drift of juveniles towards productive and oxygen rich habitats. For demersal/pelagic carnivores that undergo recruitment (from juvenile stage) over a long span of time (> 6 months), NEAS waters provide the best spawning grounds, capable of meeting their long-term nutritional demands. Therefore, NEAS waters adhere to all the requirements essential for a habitat to sustain and support the needs of juvenile fish populations during both upwelling and non-upwelling months.

Apart from reporting that carnivores dominate NEAS waters (Madhupratap *et al.*, 2001), the study also observed higher catch contribution of prawns and carnivorous cephalopods beyond 15^0N latitude. Epipelagic crustaceans such as *Acetes*, which could potentially be considered as a contender that contributes to the strong prey base in NEAS for the predator community to thrive upon, have been known to contribute heavily to the marine landings reported from Maharashtra and Gujarat. The perpetual presence of chlorophyll biomass allows for the persistence of a prey base that maximizes the likelihood of demersal adult population being well-fed. The spawning grounds for the groups considered for present study overlap with the coastal waters that satisfy the pre-requisites (availability of food, oxygenated water column) which can increase the odds of survival and sustenance of juvenile populations (King, 2013). Therefore, NEAS waters are capable of meeting the requirements of pelagic/demersal planktivore/carnivore groups (both adults and juveniles) during upwelling and non-upwelling months.

Since upwelling brings subsurface waters from the Arabian Sea oxygen minimum zone, the demersal dwellers of SEAS (especially during August and September when upwelled waters reach the surface) are known either to suffer from mass mortality against the shore or to vacate the mid-shelf depths where vertical column gets progressively filled with oxygen-deficient subsurface waters owing to strong upwelling (Banse, 1959). It has also been observed that demersal fishes (*Cynoglossus spp.*) tend to migrate away from the shores at the onset of summer monsoon only to return once its intensity has subsided (George, 1958). The onset of South West monsoon heralded the departure of juveniles of prawn (*Parapeneopsis stylifera*) towards the end of May (Menon, 1953). They were soon accompanied by older individuals (only to return in October) of the population such that a decrease in their landing off the Malabar coast was reported from July onwards. In SEAS, the sub-pycnocline oxygen deficient waters were observed to replace the oxygen-rich surface waters of the shelf whereas the upwelled waters were only able to climb up to 30m depth in NEAS waters during summer monsoon months (Shah *et al*., 2015). The study also reported upwelling signals of greater amplitude at deeper ocean layers when compared with those observed at the surface. The propagation velocity (towards higher latitudes) for upwelling signals also revealed a similar difference between the surface and subsurface waters. Towards the North of 15^0N, tilting up of isotherms was observed from August which persisted till November (Shah *et al*., 2015). Owing to more intense upwelling signals that persist in SEAS for a longer span of time (when compared with NEAS), the oxygen-rich surface waters are slowly replaced by low-oxygen containing subsurface waters along the shelf. Especially towards the terminal phase of summer monsoon, the demersal dwellers in SEAS tend to experience an abrupt decline in oxygen levels associated with their habitats. Although some species might be able to thrive in such hostile environments near the coastal waters, most of the demersal dwellers would tend to migrate towards habitats (either open seas or higher latitudes) that favor their survival. This is further supported by the sharp decline in mean standardized catch especially for demersal groups (prawns, perches and croakers) in SEAS waters (Figure 11 and Figure 12) from August to November when fishing ban remains lifted within the Indian Exclusive Economic Zone. Similar depletion of exploitable stocks of demersal fishes and prawns (manifested through decreasing trend in landing data) within the shelf waters along the West coast of India and Pakistan was reported by Banse, (1968). The situation is observed to improve once subsurface waters with low oxygen concentration retreat from the shelf.

4.6 Favorable habitat for pelagic resources

Upwelling of nutrient (inorganic) rich subsurface waters can fuel diatom-dominated algal blooms (Subrahmanyan, 1959; Subrahmanyan and Sarma, 1965) along with the support offered by nutrients released from sediments that become re-suspended in the water column due to strong onshore swell during summer monsoon (Banse, 1959). Therefore, such upwelling events that result in diatom-based algal blooms could provide ideal conditions for pelagic planktivores to thrive. The pelagic planktivores (sardines and mackerels) registered a higher catch contribution with respect to demersal groups in both SEAS and NEAS from August to November (Figure 11, Figure 12 and Figure 13) implying that their habitat had significantly smaller spatial and temporal overlap with the anoxic conditions when compared with demersal habitats. However, demersal dwellers tend to live in water column that is not as oxygen rich when compared with pelagic habitats. Hence, the sustained presence of oxygen-deficient water in the shelf (during upwelling in SEAS) forces the demersal dwellers to migrate towards hospitable waters. When such conditions overlap with spawning period of a marine resource, it may trigger large-scale mortality of eggs, resulting in acute wastage of reproductive resources (North and Houde, 2004) immediately followed by recruitment failure that gets reflected in landing data. The detrimental effects of low oxygen (< 0.2 ml/L) has been already observed for the coastal waters of Goa for croakers where the prompt establishment of seasonal sub-surface oxygen deficient environment (Naqvi *et al*., 2009) post their spawning period initiated the large-scale egg/larval mortality (North and Houde, 2004) and motivated the adults to find more hospitable waters (as indicated by the decrease in their landing data especially in the year 2001) thereby indicating that such a phenomenon is prominent in the SEAS region approximately up to 15^0N latitude (Hegde *et al*., 2016).

During non-upwelling months, SEAS waters remain nutrient-poor and incapable of sustaining primary production at a scale that could support the development of juvenile fish populations. Even when SEAS waters become nutrient-rich and sustain primary production during summer monsoon months, the strong vertical mixing/off-shore surface mass transport could possibly act contrary to the concentration/retention processes. The off-shore surface mass transport is observed to be more dominant for SEAS (Shah *et al*., 2015) when compared with NEAS especially during summer monsoon months. The strong off-shore transport associated with wind-driven upwelling also provides the possibility to advect surface chlorophyll to the open ocean (Banse,1959). Off-shore transport associated with wind-driven upwelling is limited to SEAS *i.e*. 8^0N - 15^0N latitude belt (Smitha *et al*., 2008; Muraleedharan and Kumar 1996; Shah *et al.,* 2015). Therefore, the likelihood of such advection of biota due to off-shore surface mass transport is higher in SEAS (with respect NEAS surface waters).The strong vertical mixing associated with upwelling in SEAS could result in the potential removal of chlorophyll biomass from surface waters to deeper layers with restricted access to sunlight. In the absence of retention/concentration processes associated with SEAS upwelling, fish-larvae are left with a short span of time (< 4 months) to undergo its recruitment to adult fish-stock. Pelagic planktivores (for example Sardines) which can do so, thrive in such waters (George, *et al*., 2012). The dominance of zero-year class in the sardine landing data (Balan, 1984; Raja, 1969; Longhurst and Wooster, 1990) is another evidence that corroborates the former statement.

SEAS is well capable of sustaining the pelagic groups (both planktivore and carnivore) during summer monsoon months. However, demersal dwellers (juveniles/adults) appear to thrive in NEAS waters since habitats located to the North of 15^0N latitude has a higher likelihood of entraining surface/column waters with bearable oxygen levels (> 0.5 ml/L) apart from being productive enough to sustain the metabolic demands of juveniles and adults. The establishment of conducive environment for demersal carnivore group (juveniles/adults) in NEAS waters could contribute to the skewness of catch composition towards carnivore spectrum towards North of 15^0N latitude.

5 Concluding remarks

We believe that oceanographic forcing (summarized in Table 2) has a strong bearing on seasonality in catch composition. In this study, we have attempted to explore the putative link by identifying the key characteristics of coastal waters of Arabian Sea that render them suitable to meet the demands of fish population (both juveniles and adults). Although skewness in catch composition (towards carnivore spectrum) across 15^0N latitude was reported earlier (Madhupratap *et al*., 2001), the driving factors responsible for such unique catch composition have not been investigated hitherto. The study concludes that anoxic conditions associated with intense seasonal upwelling in SEAS waters leads to the reduction in the vertical extent of demersal carnivore habitats. NEAS waters cater to the nutritional requirements of juvenile demersal carnivore population as it supports primary production both during summer and winter monsoon months (Madhupratap *et al.,* 1996 ; Kumar *et al.,* 2010). The perpetual presence of chlorophyll biomass allows for the persistence of a prey base that maximizes the likelihood of demersal adult population being well-fed. The poleward directed West India Coastal Current facilitates the passive drift of juveniles towards productive and oxygen rich habitats in NEAS waters. For demersal/pelagic carnivores that undergo recruitment over a long span of time (> 6 months), NEAS waters provide the best spawning ground capable of meeting their long-term nutritional demands. Pelagic planktivores thrive in SEAS, where seasonal upwelling supported primary production remains the norm, owing to their relatively short recruitment span (< 4 months). Unlike SEAS, NEAS waters are found to provide suitable environment geared towards the successful larval recruitment, sustenance and survival of the demersal carnivore group (King, 2013). This could act as a forcing function in driving the annual catch composition of landing data registered in NEAS waters toward carnivore spectrum.

Table 2. Oceanographic forcing and biological field characterizing North East Arabian Sea (NEAS) and (South East Arabian Sea) SEAS

Oceanographic forcing/ Biological field	**NEAS**	**SEAS**	**Remarks**
Surface density	Higher	Lower	Allows the eggs of pelagic and demersal fish to remain suspended closer to surface
Surface Currents	Poleward during Winter monsoon	Equator-ward during summer monsoon	Causes drift /aggregation of fish eggs/larvae nearer to habitats with better feeding conditions
Upwelling intensity (based on Sea surface height anomaly, Isopycnals)	Low and highly localized	High and more widespread	Upwelling based biological production dominates SEAS during summer monsoon. Anoxic conditions prevail in the SEAS water column during upwelling months whereas NEAS entertains oxygen-rich water column at least up to a depth of 30 m from the surface.
Surface wind	North-eastward aerosol laden dry winds during winter monsoon	South-westward moisture laden wind during summer monsoon	Contributes to primary production in NEAS/ SEAS during winter/summer monsoon months
Likelihood for Tidal current amplification	High	Low	Contributes to nutrient enrichment of shelf waters in NEAS.
Continental shelf	Wide	Narrow	Improves the likelihood for nutrient-enrichment of shelf waters through tidal forcing

Off-shore surface mass transport	Weak during summer monsoon	Strong during summer monsoon	Serves as a concentration process by containing the primary production within coastal waters
Chlorophyll biomass	Sustained primary production mostly throughout the year	High primary production observed during summer monsoon	Breeding season of fish groups overlaps with summer monsoon when eastern Arabian Sea surface water is productive enough to meet the demands of juveniles

Regional differences in abundance of pelagic carnivores can also contribute to the bias in catch composition across 15^0N latitude. However, since the vertical extent of their habitats share very little overlap with the anoxic conditions associated with upwelling, such conditions are assumed to have very little impact upon their landing. Hence, such groups have not been considered for the current study. Moreover, the landing data could contain marine resource caught from open seas. Although the study used landing data standardized across multiple fishing gears in an attempt to remove the biases in data introduced due to the differences in effort/fishing gears employed, market demand (which is not taken into account in the current study) could also be another key player that sways the catch composition in favor of a given marine resource of preference at a given point in time and space. A strong decrease in landings can also occur due to overexploitation of marine resources. Such drawbacks need to be carefully considered and the bias they introduce in the landing data needs to be addressed by future endeavors.

Within the exclusive economic zone (up to 200 nautical miles from coast), maximum fishing is undertaken. The territorial waters (up to 12 nautical miles from the coast) come under the jurisdiction of the respective maritime States. As per the State Marine Fisheries Regulation Act formulated based on the guidelines recommended by Central Ministry, trawling remains banned from June 14^{th} (mid-night) to July 31^{st} during South West monsoon period, which coincides with the breeding season for commercially important species. However, the breeding season for certain fish populations occur during winter monsoon, when the season remains open for mechanized fishing. The study suggests that trawling ban should also be enforced during winter monsoon, which might benefit carnivore species as well as the fishing community in the long term. However, the breeding behavior and distribution pattern of commercially important species are not uniform in general. There is a need for ecosystem based management where regulations associated with marine protected areas (where fishing is prohibited), and seasons during which trawling ban is enforced locally, ought to be formulated based on indicators that reflect the health of the ecosystem.

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CHAPTER

36

Freshwater Fishery Biology and Conservation

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INTRODUCTION

Even though the earth is a “water planet”, with two thirds of its surface covered by the liquid, very little of it qualifies as fresh water. Nearly 97% of the water on this planet is, to varying degrees, saline. Of the three percent that is considered fresh water, defined as water with salinity less than 0.05%, nearly two thirds is frozen in the form of polar ice caps, permafrost, glaciers and snow and close to a third is in the form of ground and soil water. Of the remainder, some is in the form of clouds, as water vapour. Surface fresh water, in the form of lakes, rivers and swamps; thus accounts for less than 0.01% of the total available water on earth. And this miniscule volume of water is home to over 40% of known fish diversity on earth. The sheer diversity of freshwater fish species is testament to the wide variety of freshwater ecosystems, widely scattered across the surface of the earth, which are potent drivers of evolution and rapid speciation.

Fish, and other aquatic life, which are integral components of freshwater ecosystems, provide locally important fishing opportunities, which are often important to the survival of indigenous human populations. Inland fisheries contribute roughly 10% to the global fisheries catch (World Bank 2012), but they are of great importance, especially in economically backward regions as a means of ensuring food security. Unlike marine fisheries, which are industrialised, inland fisheries are often artisanal; with the catch mostly being disposed off locally. According to FAO definitions, inland fisheries can be broadly classified as recreational, subsistence or commercial.

Recreational fisheries are those which are not primarily intended to meet nutritional needs and where the catch is generally not sold. Such fisheries may be of the catch and release or catch and keep variety, and often involve captive bred fish which are stocked into natural or artificial water bodies. Prominent examples include the mahseer fishery in Asia, trout and salmon in Europe and North America and tigerfish in Africa. The targets of recreational fisheries are often large growing fish of striking appearance and as such are ideally suited to serve as flagship species for conservation efforts.

Subsistence fisheries refer to activities which address an individual’s nutritional needs and where the catch is not sold at a formal market, but is consumed by the fisher or their immediate family and friends. However, subsistence fishers may also set aside a portion of their catch to be sold in local markets and thereby supplement their basic livelihood. Obscure and often overlooked locations such as ponds, streams and rice paddies are also capable of supporting subsistence fisheries. Due to these factors, identifying and quantifying subsistence fisheries is often difficult. Attempts have been made to quantify subsistence fisheries based on consumption data, but difficulties in accurately identifying the source fishery from consumption data mean this data is of dubious value (Welcomme, 2011). E.g. studies on fish consumption in Vietnam suggest inland capture fisheries production is up to five times greater than what is suggested by fisheries statistics (World Bank 2012).

Commercial fisheries are activities where the catch is primarily sold in domestic or export markets. Commercial fisheries in inland waters are usually on a small scale (Welcomme, 2001), although the kinds of gear used can vary from simple to complex. Commercial inland fisheries are often well regulated, and while by-catch exists, they are usually utilised to a greater extent than in marine fisheries. Commercial inland fisheries are of great socioeconomic importance, especially to rural households in developing economies (Welcomme et al., 2010), and contribute significantly to the livelihoods of millions of people.

Freshwater fishes fill a wide range of roles and services which are crucial to the long term health and survival of their ecosystems. In addition, these species are also essential for fulfilling the nutritional requirements of billions of people, especially in Africa and Asia. Inland fisheries account for a third of the world's small scale fish catch and are estimated to provide employment for about 60 million people (UNEP 2010). Conserving freshwater fish diversity is, therefore, of paramount importance to ensure the health of freshwater ecosystems and the nutritional security of a large proportion of humanity.

THE EXTENT AND DISTRIBUTION OF THREATS TO FRESHWATER FISHES

Species Traits and the Risk of Extinction

Myers (1938) classified freshwater fishes as "primary", meaning species with little or no tolerance for seawater now or at any point in their evolutionary history (e.g. Cypriniformes) and "secondary", meaning fishes that can or previously possessed the ability to tolerate seawater. Primary freshwater fishes, therefore, have limited natural distributions, with little opportunity for dispersal or natural range extension. The majority (93) of the 138 known freshwater fish families are considered primary freshwater fishes (Berra, 2001), and therefore catastrophic disturbances to a river basin or region can have long-lasting impacts on the diversity and composition of fish communities. Winemiller & Rose (1992) identified certain combinations of traits in the life histories of species, which could influence the risk of extinction when faced with adverse conditions. Opportunistic species, which are often associated with frequently disturbed habitats, are characterised by small adult size, early maturation and low juvenile survival. Equilibrium species, associated with stable habitats, are characterised by small be medium adult size, low fecundity and high juvenile survival, often as a result of intensive brood care. Periodic species are characterised by a large adult size, late maturation, high fecundity and low juvenile survival and are associated with habitats exhibiting seasonal (or periodic) variation. Equilibrium and periodic breeding species are considered to be at greater risk of extinction from environmental changes. Distributional range is also a key predictor of extinction risk. Species with limited ecological and geographical ranges are more vulnerable due to lower population sizes and often specialised habitat requirements. Body size is another trait associated with risk of extinction, with both small and large growing species at greater risk. Small bodied fish are at greater risk of impact from exotic species, being more susceptible to predation and less likely to compete (McDowall, 2006). Large bodied species are usually long lived, with delayed maturity and extended migration and dispersal pathways. They are at risk from fishing pressure and habitat modification (Stone, 2007).

Human impacts on freshwater fishes

As of 2013, the International Union for the Conservation of Nature (IUCN) have assessed 46% of the known freshwater fish diversity of the time and identified major threats and risk of extinction. Of the species that have been assessed, 31% were classified as Critically Endangered, Endangered or Vulnerable and are threatened with extinction (IUCN 2013). An additional 69 species were assessed as Extinct or Extinct in the Wild. This is a relatively high level of threat, compared to that for terrestrial vertebrates such as birds (13%) or mammals (20%). Thieme et al. (2011) summarise the major threats to freshwater ecosystems as due to;

(a) The role of freshwater ecosystems as sinks for terrestrial runoff which includes pollutants, toxins and pesticides

(b) Threats from human use of freshwater resources for irrigation, hydel power and transport

(c) Harvest pressure due to fishing activities

(d) High levels of connectivity between freshwater ecosystems which facilitate the transport of pollutants and exotic species

Threats to freshwater fish species tend to rise where rich species diversity coincides with dense human population, intensive resource use and development pressure. Human activities are now the leading cause of reductions in the diversity and abundance of freshwater fish species across the globe (Dudgeon 2011). The adverse impacts of human activities are not inevitable, but are the outcome of how society values and treats ecosystems. Many impacts on freshwaters can be significantly minimised or mitigated, thereby facilitating conservation.

Ecosystem destruction is the most extreme endpoint of cumulative human impacts. A failure to associate the cumulative impact of local actions on larger scales can result in ecological collapse. Urban and agricultural development can physically and ecologically destroy river basins by combination of factors which include habitat degradation, changes to local drainage patterns, reduction in groundwater recharge, channelization and the total removal of surface water through pumping. Surface mining as well as abstraction of river sand can also degrade ecosystems by changing run-off characteristics and reducing percolation. Fish diversity usually decreases with agricultural intensification. Uncontrolled dewatering also leads to increased salininsation, rendering the habitat unsuitable for primary freshwater fishes and irreversibly changing community composition (Beatty et al., 2011). The combination of increasing human populations and climate change can expand the scope of impact of such processes.

Water resource development for agriculture, drinking water and flood mitigation creates further habitat degradation. Barriers to migration and population fragmentation can result from the construction of impoundments and dams as well as the degradation of stream reaches. River systems around the world have been fragmented by the construction of over 50,000 large dams and an unknown number of small impoundments, which act as barriers to fish migration (Richter et al., 2010). Dams are barriers to migration between foraging and breeding grounds for both diadromous and potamodromous species. While some attention has been given to upstream migration of fishes and led to the development of structures such as fish ladders, little attention has been paid to downstream migration of fish, eggs and larvae. The life cycles of many species are closely linked to seasonally variable flow regimes, with critical cues for various life history stages tied to patterns of flow, temperature and photoperiod (King et al., 2003). Flow management for human purposes tends to minimise variations in flow, reducing the peak and increasing the minimum. Flow is also a major determinant of physical habitat and determines the suitability of habitat for specialised species. In addition to reductions in flow, dams also have downstream impacts resulting from altered sediment transport dynamics, the results of which can complex and difficult to manage. The altered conditions in impounded rivers tend to exclude native specialists in favour of generalist species. It has been argued that global homogenisation of river discharge tends to homogenise global fish fauna (Moyle & Mount, 2007), favouring ubiquitous invasive species such as common carp and tilapia.

Water pollution is a complex topic involving a diversity of chemicals and varied impacts. Because freshwater bodies are tightly linked to surrounding catchments, any change to the condition of the catchments, such as clearing of vegetation or changes to drainage patterns will result in changes to the chemical composition of water from the catchment. Even minor and diffuse chemical releases can have significant cumulative impacts, especially if there is bio accumulation within the ecosystem. In some cases, a single point source of pollution, e.g. the release of mine tailing waste, can have devastating effects over an entire river system. Numerous chemical compounds enter freshwater ecosystems from a variety of sources including the atmosphere, sewage, urban and agricultural runoff, and toxic leachate from mines and industry. Persistent chemicals, such as mercury, create legacy effects due to bioaccumulation, that persist long after the source of pollution has been removed. Increasing levels of mercury have been reported from fishes and top predators (including humans) in the Amazon basin, suggesting bioaccumulation and biomagnifications pose a significant threat (Ouboter et al., 2012). Non-toxic contaminants also pose a significant risk to freshwater ecosystems. Urbanisation and intensive agriculture introduce nutrients into the water, potentially causing dramatic changes to food webs. Inorganic sediments are another significant input, with the potential to interact synergistically with nutrients. Acidification of waterways is also a problem in many areas, usually as a result of industrialisation, although it is difficult to quantify the impacts of non-toxic pollutants on aquatic biota.

Fisheries, aquaculture and the introduction of exotic species can change the structure of freshwater fish communities. Our understanding of the impacts of the direct exploitation of freshwater fishes is somewhat poor, and direct impacts are often obscured by other interacting factors (Welcomme et al., 2010). It is also important to note that fisheries can also have significant indirect benefits to ecosystems such as incentives to protect waterways and an awareness of the threats to ecosystems. Commercial capture fisheries tend to focus on large individuals and species and overfishing often contributes to declines in their numbers. As larger species are depleted, attention shifts to smaller less desirable species, resulting in a pattern of fishing down the food web in freshwater multispecies fisheries. The effects of fishing, such as altered population structure, are usually considered less harmful than compared to impacts of habitat degradation and are potentially reversible with appropriate management. Aquaculture has the potential to supplement fish populations in high pressure high yield fisheries, but is associated with a range of problems. Aquaculture competes for the same resources as wild species and a tendency to focus on high value large species ignores the large numbers of smaller fish that characterise freshwater capture fisheries. Significant drawbacks of aquaculture also include the spread of exotic species and disease. Invasive alien species are a major cause of biodiversity loss worldwide and among the least reversible human impacts (Lepriuer et al., 2008). The ecological risk and impact of most non-native introductions are poorly understood, partly due to a lack for standard methods for quantifying impact (Lapointe et al., 2012). The positive relationship between economic activity and non-native fish diversity is of particular concern in areas with rich natural diversity and rapidly growing economies.

CONSERVING FRESHWATER FISH DIVERSITY

As the most diverse and biogeographically distinct group of vertebrate taxa, freshwater fish provide unique insights into biogeographic patterns and evolutionary processes. Freshwater fish biogeography reflects continental drift and the co-evolution of multiple species over long time scales. Freshwater fish also contribute to the quality of human life in a variety of ways. They are critical to the cultural heritage, nutrition and economy of many places around the world. Loss of species reflects a loss of ecological function, which ultimately reduces the stability, value and support provided by such ecosystems to human society. The conservation and protection of freshwater fish involve some real or perceived costs at the individual and community level. The great centres of global freshwater fish diversity, representing nearly 70% of known freshwater species, are still relatively undisturbed. Focusing efforts on these discrete areas will help optimise the conservation of global diversity. Large scale development in tropical South America and Indo-Burma may prove harmful to the survival of many freshwater fishes. Climate change, coupled with sea level rise, also poses a threat to these low lying areas.

The sheer diversity of freshwater fish species, and the genetic distinctness of populations within large river basins mean that identifying and protecting all significant populations is a daunting task. Small fish species, due to their high diversity, restricted distributions and specialised life histories are faced with a disproportionately high threat of extinction. Considerable, often cryptic, within and between species diversity requires specialist taxonomic skills to recognise the subtle differences between distinct populations. Such taxonomic skills are in limited supply, thus increasing the risk of unrecognised loss of diversity. Developing taxonomic expertise is often an important first step in ensuring the genetic integrity of populations and species.

The impacts of dams on river systems can be mitigated to some extent by the inclusion of fish ladders in the construction, increasing minimum flows and mimicking flow seasonality by periodic release of high flows. There is general agreement amongst scientists and fisheries managers that in order to protect freshwater biodiversity, we need to incorporate elements of natural flow variability such as magnitude, frequency, timing, duration and rate of change in flow events (i.e. floods and droughts) (Arthington 2012). There is also evidence to suggest variations in water temperature must also be considered in tandem with flow in order to maintain habitat quality downstream of dams.

Little thought has been spared for conservation or biodiversity criteria throughout most of the history of artificial propagation and stocking. Globally, production by artificial propagation runs into the billions of individual fish. The potential economic benefits of artificial propagation include increased harvest opportunities, mitigation of losses due to human activities, and employment opportunities. Potential ecosystem benefits include reduced short term extinction risks for threatened populations, maintenance and recovery of depressed populations, recolonisation of depleted habitats, and reduction of harvest pressures on natural populations. Any potential introduction, re-introduction, translocation or stock transfer must first assess the risk benefit conflicts of the programme. For truly effective conservation programmes, it is essential to look at propagation, translocation and re-introduction through the lens of the ecosystem rather than on the species of interest.

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CHAPTER

37

Marine Fishery Regulations and Policies for Conservation in India

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Introduction

India, being one of the largest marine fisheries in the world, has high stakes in managing its coastal and marine resources. The marine resources in India are highly diverse comprising of an exclusive economic zone of 2.02 million km^2 besides a continental shelf area of nearly 0.50 million square kilometers. The capture fisheries sector in India, though experienced a rapid expansion in the recent decades with the advent of mechanized fishing during 1980s, has started showing signs of over capitalization and consequent crises. Experts in the field have already highlighted the impending problems such as declining catch rate and diminishing returns, overfishing and /juvenile fishing leading to depletion of fish stock, rampant destruction of marine biota due to high-intensity trawling, and so on (Devaraj and Vivekanandan,1999; Ramachandran, 2004). The imminent crisis is increasingly getting reflected through frequent conflicts between various groups/factions of fishermen/vessel operators over their rights and shares over the resources. These circumstances echo the need for a strong regulatory and management regime for protecting and preserving the maritime resources of the sub-continent. Though India is not new to regulations in fisheries sector with a number of laws and rules in place for more than a century, the emerging scenario merits a relook into the existing regulatory framework. Against this backdrop, this chapter presents global approaches to marine fisheries regulations along with a broad overview and critical appraisal of India's marine fishery regulations and policies aimed at conservation and sustainable development.

Approaches and tools to fishery regulations

A wide variety of approaches and tools are used for regulating fisheries across the world. As the primary aim of regulating a marine fishery is to maintain a sustainable level of biomass and productivity in the wild stock, efforts in this direction are mainly directed to limit the rate of extraction. The basic scientific concept followed in this context is the 'maximum sustainable yield (MSY)' which is the maximum level at which a resource can be routinely exploited without long-term depletion. The idea was evolved in fisheries in the early 1930s, and attained popularity in the 1950s with the advent of 'surplus production models' capable of actually estimating the MSY based on oceanographic and marine data. However, subsequent assessments revealed that while establishing a sustainable level of harvest as goal with intuitive appeal, the pursuit of MSY ignores many relevant economic and social factors that are critical to the sustainability of a fishery (Larkin *et al*, 2011). A new concept namely, maximum economic yield (MEY) was introduced that defined the level of harvest or effort that maximizes the sustainable net returns from fishing (Grafton *et al*,

[1] This chapter is a condensed version of the authors' article entitled 'Taming the fishing blues: Reforming the marine fisheries regulatory regime in India' published in *Economic and Political Weekly*, Vol. 52 (45), 2017.
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2006). This approach picked up momentum with developments in the area of bio-economic modeling that combines the underlying stock dynamics with the harvest function and the costs of harvest and economic value of the extracted resources. An illustration on how MSY and MEY compares with each other is presented in Figure 1. Declaration of total allowable catch (TAC) limits, especially by temperate fisheries administrations, is generally based on any of the above two concepts. MSY/MEY can be achieved through alternative strategies such as limiting access to the resources, setting caps on quantity harvested, limiting the fishing efforts, maneuvering the area and time of harvesting so as to avoid spawning and juvenile fish, and so on. These basic strategies became the guiding principles behind fishing regulations that forms essential components of all major fisheries management programs in the world. Accordingly, approaches to fisheries regulation can be broadly classified into five categories, viz., (i) Access-control based (ii) Output/catch-based (iii) Input/effort-based (iv) Temporal and (v) Spatial. However, such a classification is not water-tight and is subject to changes depending upon contexts. While the first three approaches are primarily directed to limit the rate of extraction from the stock, temporal (mainly seasonal bans) and spatial approaches generally target to minimize destruction to sensitive stocks (endangered species, spawning and juvenile fish).

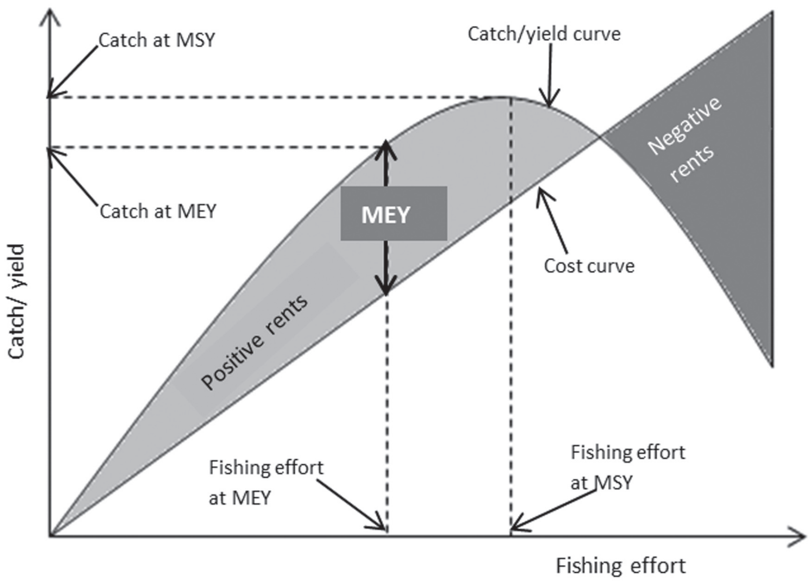

Figure 1. Maximum sustainable yield (MSY) and maximum economic yield (MEY)
Source: World Bank (2009)

A brief account of the main fishery regulatory tools that fall under the above five approaches along with a few notable examples is presented in Table 1. Among the various measures, access control is one of the most basic and easy-to-implement regulation that includes tools such as licensing and registration that limit fishing access based on a set of basic minimum requirements. It also includes options such as limited entry permits issued to impose severe access restrictions, and those like group fishing rights and territorial use rights for fishing (TURFs) that are restricted to specific communities or beneficiary groups. Output-based regulatory tools include collective/individual catch quota, vessel catch limits and minimum size limits. Catch quota are generally fixed based on TAC estimates derived based on the concepts of MSY/MEY and are subsequently rationed among beneficiaries based on certain qualifying criteria. The quotas are either transferable or non-transferable depending on the degree of regulation. Minimum size limits, another output-based regulation, are mainly set to prevent harvesting of juvenile fish thereby to hasten rebuilding of excessively exploited stocks. Nevertheless, output control measures are data intensive and requires substantial amount of resources for their implementation, thus limited only to a handful of advanced fisheries. Input-controls focus on restricting the types of inputs as well as effort involved in the stock extraction process and include gear restrictions that set limits on the type, designs and mesh-size of the gears used, engine power restrictions, as well as size restrictions on fishing vessels. Though they are relatively easier and less costly to implement as compared to output-based measures, one major demerit is the difficulty associated with assessing the extent of control on each input so as to derive desired results (FAO, 1997). Temporal controls are widely adopted across the world, wherein, the idea is to regulate resource extraction during specified seasons of the year or to fix time limits to fishing. Seasonal fishing bans, a common temporal strategy, is adopted both in temperate and tropical waters to minimize destruction of spawning population. Spatial restriction approach on the other hand, includes alternative tools such as designating marine protected areas (MPAs), temporary area closures and spatial zoning. MPAs have received considerable attention in the recent times and are increasingly employed world-wide as an ecosystem-based management strategy to conserve marine resources and to prevent the degradation of sensitive marine ecosystems through coastal protection, habitat restoration and biodiversity conservation (Halpern, 2003; Kaplan *et al*, 2015).

Table 1. Major tools for regulating capture fisheries

Regulatory approach	Specific tool	Description	Major examples (with year of first introduction)
	License	License is the basic access requirement for a fisher to undertake fishing.	Almost all major fisheries in the world.
Access controls	Registration	Registration of fishing vessels for identification purpose is mandatory by law in most fisheries.	Almost all major fisheries in the world.
	Limited entry permits	Holders of the individual entry permits are only allowed to compete for harvests from a common pool.	Salmon fishing licenses (Alaska, 1974, British Columbia, 1968); Western Australia rock lobster (1963).
	Group fishing rights/ fishing cooperatives	Limited entry permit holders agree on a harvesting system usually by written contract.	Pacific whiting Conservation Cooperative (1998); Bering Sea Pollock Co-ops (1999).

	Territorial use rights for fishing (TURF)	Access to fishing areas limited by custom or law to members of a village, tribe or other groups.	Community-based TURFs in Oceania and Japan; Coromandel coast fisheries, Tamil Nadu, India.
	Collective catch quota	Aggregate catch quotas allotted to specified beneficiary groups.	Western Alaska Community Development Quotas (1994).
	Individual catch quota	Species-specific catch quotas (in terms of weight) allocated to individuals. They are generally transferable / tradable.	Individual transferable quota (ITQ) programs in Alaskan halibut/sablefish fishery (1995); ITQs in Southern Australian shelf for bluefin tuna (1983).
Output/catch-based	Vessel catch limits/ quotas	Catch quotas specific to vessels.	Individual Vessel Quota (IVQ) system for the ground fish trawl fishery in the British Columbia (1997).
	Size restrictions	Minimum legal sizes (MLS) specified to individual fish species to prevent juvenile fishing.	Minimum legal size (MLS) restrictions in Kerala fisheries, India (2015); MLS restrictions in Baltic cod trawl fishery (1994).
Input/effort-based	Gear restrictions	Restrictions on the type and designs as well as mesh-size of the fishing gear used.	Mesh-size regulations in Baltic cod trawl fishery (1994); Mesh-size limits under the marine fishery regulatory acts of India.
	Engine power restrictions	Regulations by placing an upper-limit on the engine horse power.	Common Fisheries Policy of Council of the European Union, 2009.
	Vessel size restrictions	Size restrictions on fishing vessels applicable to specific fishery fleets, especially in terms of their length/ tonnage.	British Columbia Ground fish trawl fishery (1997); Nova Scotia ground fish fishery, Canada (1989).
	Seasonal fishing ban	Fishing bans imposed during specified seasons in a year, mainly to prevent fishing during spawning.	Seasonal fishing bans in eastern and western costs of India (1980 onwards); Closure of North sea beam trawl fleet to cod fishery (2001).
Temporal restrictions	Fishing duration restrictions	Limiting the duration of fishing by an individual/ vessel (eg: limits on hours/ day, days/season, time away from port, etc.)	Effort quotas (fishing duration) for regulating demersal fish stocks in the Faroe Islands, Denmark (1996); 'Days-at-sea' regulations for New England ground fish fleet (1995).
	Fishing time restrictions	Restrictions to fishing during particular time of the day (eg: regulation of night fishing).	Prohibition of trawl net operations between 6 pm and 6 am in Maharashtra coast, India (1981); Night fishing ban in Lamu, Kenya (2011).

	Marine protected areas (MPA)	A protected area where fishing is prohibited. MPA area divided into six categories by IUCN based on strictness of the protection regime.	MPAs in New South Wales, Australia (2002); Florida Keys National Marine Sanctuary, USA (2000); MPAs in the Indian peninsula (1978).
Spatial restrictions	Temporary area closures	Temporary area closures are practiced mainly to protect juveniles in specific areas where certain species come for spawning.	Area closures to protect octopus in Velondriake marine area in Madagascar (2004).
	Spatial zoning	Restricting access to different groups of fishers (artisanal fishers *versus* mechanized fishers) based on distance from shore/ depth of water.	State marine fisheries regulations, India (1980).

Source: Parappurathu and Ramachandran (2017)

Fishery regulations in India

Marine capture fishery in India is governed by a number of rules and regulations which are put in place from time to time with cross cutting mandates and objectives. The pioneering attempt to regulate fishing in India was the introduction of The Indian Fisheries Act, 1897 by the then British administration. This was followed by several local regulations promulgated by various princely states in the subsequent years of British Raj. In the post-independence era, the enactment of two crucial laws, viz., The Territorial Waters, Continental Shelf, Exclusive Economic Zone and other Maritime Zones Act, 1976 and Maritime Zones of India (Regulation of Fishing by Foreign Vessels) Act, 1981 has significantly altered the way fishery in the country is regulated. These Acts which deal with demarcation of maritime zones for fishing and ocean administration were the offshoots of the UNCLOS negotiations. Other important legislations/policies passed during the 1970s and afterwards and which are relevant for marine fishing activities include, Wildlife Protection Act, 1972; The Forest Conservation Act, 1980; The Environment (Protection) Act, 1986; The Coastal Regulation Zone (CRZ) notification, 1991; New Deep Sea Fishing Policy, 1991; Biological Diversity Act, 2002; Comprehensive Marine Fisheries Policy, 2004; notifications declaring selected coastal areas as MPAs from time to time, and so on. The latest effort in this direction is the National Policy on Marine Fisheries, 2017 which was notified on 28th April, 2017 (GoI, 2017).

As per the clauses under the Act of 1971, the areas up to 200 nautical miles from the territorial sea baseline is designated as the Exclusive Economic Zone (EEZ), wherein the country has sovereign rights for the purpose of exploration, exploitation, conservation and management of the natural resources as well as for producing energy. Areas up to 12 nautical miles (nm) from the baseline are designated as territorial waters. As per the Seventh Schedule of the Constitution of India, the states have the jurisdiction to govern fishing and fisheries in the territorial waters, whereas the union government reserves its jurisdiction beyond territorial waters, i.e., between 12 nm and 200 nm. The marine fishing activities within the territorial waters of maritime states are governed by the respective Marine Fisheries Regulatory Acts (MFRAs). Kerala and Goa were the pioneering states to pass their own MFRAs in the year 1980, which was followed suit by other maritime states in the subsequent years. The MFRAs contain several provisions to regulate, restrict or prohibit unsustainable / destructive fishing practices, to define access rights, to impose spatial and temporal fishing restrictions and to make licensing and registration of fishing vessels compulsory. Clauses to penalize non-compliance and appellate provisions are also inbuilt in them so as to ensure fair governance of fishing and related activities. The specific details of the legislations and regulatory provisions contained therein with respect to the maritime states of India are presented in Table 2.

Table 2. Capture fisheries regulatory framework in maritime states of India

Maritime State	Access controls	Temporal controls	Spatial controls	Input/ effort-based	Output/ catch-based	Legislation/s in force
Gujarat	Registration and licensing of fishing vessels.	Seasonal fishing ban (SFB) (Jun 1 – July 31, 61 days)	Artisanal: up to 9 km; Mechanized: beyond 9 km.	Square mesh of minimum 40 mm size at 2003. cod end need to be used for trawl net; Gillnet with mesh size less than 150 mm prohibited.	-	The Gujarat Fisheries Act,
Maharashtra	-do-	SFB (Jun 1 – July 31, 61 days); Mechanized vessels with trawl net prohibited between 6 pm and 6 am.	Mechanized (trawl net) : beyond 5-10 fathom depth in specified areas; Mechanized (any type with more than 6 cylinder engines): beyond 22 km.	Use of purse-seine gears by mechanized vessels at specified coastal zones prohibited within territorial waters.	-	Maharashtra Marine Fisheries Regulation Act, 1981 (Amended in 2015).
Goa, Daman & Diu	-do-	SFB (Jun 1 – July 31, 61 days)	Artisanal: up to 5 km; Mechanized: beyond 5 km.	Mesh-size limits of 20 mm for prawn and 24 mm for fish.	-	The Goa, Daman and Diu Marine Fishing Regulation Act, 1982 (Amended in 1989).
Karnataka	-do-	SFB (Jun 1 to July 31-61 days)	Artisanal: up to 6 km or up to 4 fathoms (whichever is	Ban of cuttle fish fishery using FADs; Ban on light fishing.	-	The Karnataka Marine Fishing Regulation Act, 1986.

			farther); Deep sea vessels (up to 50 feet length): beyond 6 km Deep sea vessels (>50 feet length): beyond 22 km.			
Kerala	-do-	SFB (Jun 15-July 31, 47 days) [1]	Artisanal: 32 -40 m depth in the first zone[2] and 16-20 m depth in the second zone; Mechanized vessels (< 25 GRT): 40-70 m depth in the first zone and 20-40 m depth in the second zone; Mechanized (> 25 GRT): beyond 70 m depth in first and beyond 40 m depth in second zone.	Mesh-size regulations: code end minimum mesh size of bottom trawl net-35 mm; ring seine and driftnet minimum mesh size – 20mm.	Minimum legal size for 58 fish and shell-fish species notified to control juvenile fishing.	The Kerala Marine Fishing Regulation Act, 1980 (Amended in 2013 and 2017).
Tamil Nadu	-do-	SFB (April 15 to June 14, 61 days)	Artisanal: up to 5 km. Mechanized: beyond 5 km; Fishing within 100 m below a river mouth is prohibited; The number of mechanized fishing vessels permitted in any specified area subject to restrictions.	No fishing gear of 100 mm mesh from knot to knot in respect of net other than trawl net to be used; Pair trawling and purse seining are prohibited.	-	Tamil Nadu Marine Fishing Regulation Act, 1983 (Amended in 1995; 2000; 2011; 2016).
Andhra Pradesh	-do-	SFB (April 15 to June 14, 61 days)	Artisanal: up to 8 km; Mechanized	A minimum 15 mm limit for mesh-size	-	The Andhra Pradesh Marine Fishing

			(< 15 m OAL): 8-23 km; Mechanized (< 15 m OAL): beyond 23 km.	for any gear; Shrimp trawlers not allowed without turtle-exclusion device (TED).		(Regulation) Act, 1995 (Amended in 2005).
Odisha	-do-	SFB (April 15 to June 14, 61 days)	Artisanal: up to 5 km; Mechanized (<15 OAL): 5-10; Mechanized (>15 OAL): beyond 10 km.	-	-	Marine Fishing Regulation Act, 1981 (Amended in 2006).
West Bengal	-do-	SFB (April 15 to June 14, 61 days)	Artisanal & mechanized crafts with < 30 HP engine: up to 18 km; Mechanized crafts with >30 HP engine: beyond 18 km.	Mesh size regulations for specific gears: minimum 25 mm for gillnet/shore seine/drag net; 37 mm for bag net/ dol net; Standard trawl net fitted with TED to be used.	-	The West Bengal Marine Fisheries Regulation Act, 1993.
Andaman & Nicobar islands	-do-	SFB (April 15 – June 14, 61 days)	Artisanal & mechanized crafts with < 30 HP engine: up to 6 nm; Mechanized crafts with >30 HP engine: beyond 6 nm.	Standard trawl nets fitted with TED; Gillnets, shore seines and dragnets with mesh sizes above 25 mm only permitted.	-	The Andaman and Nicobar Islands Marine Fisheries Regulation Act, 2003 (Amended in 2011).
Lakshadweep	-do-	SFB (Jun 1- July 31, 61 days)	Use of purse seine, ring seine, pelagic, mid water and bottom trawl of less than	-	-	Lakshadweep Marine Fishing Regulation Act, 2000.

	20 mm mesh size, use of drift gill net of less than 50 mm mesh size and shore seine of less than 20 mm mesh size are prohibited in specified areas.

Source: Updated from Parappurathu and Ramachandran (2017)

Regulatory provisions under the MFRAs: A critical appraisal

MFRAs have been found effective to a great extent in regulating fishing within the territorial waters. These legislations make use of a variety of regulatory approaches such as access control, input/effort-based restrictions, spatial as well as temporal restrictions outlined above. However, output/catch-based controls have been sparsely used by the states (except in Kerala, where MLS for fish species are notified in 2015). Provisions for compulsory registration and licensing of fishing vessels, which are the basic access control measures used world over, finds place in the MFRAs of all maritime states and UTs. Temporal restriction of mechanized fishing or seasonal fishing ban (SFB) is another tool adopted across the maritime regions of India. The basic rationale is to restrict fishing activities during the time when most marine fish species undergo peak spawning so as to ensure natural replenishment of fish stock. Gujarat, Goa, Maharashtra, Kerala and Karnataka have been diligently practicing SFB for more than 2 decades and other states have joined force during the later years. The criteria in fixing the closure periods and the type of fishing activities restricted during SFB varied across states. However, to avoid conflicts of fishermen from different states, the Union Government appointed a committee in May, 2013 under the Chairmanship of Director, CMFRI to suggest uniform closure period for India's EEZ. The committee, based on scientific facts on spawning periods and other relevant details as well as stakeholder consultations across states, recommended a seasonal closure for 61 days (GoI, 2014). Based on this, the government fixed the ban period during April 15 till June 14 in East Coast and during June 1 to July 31 in the West Coast, since 2015. However, within their territorial waters, the States reserve the rights to decide on the fishing ban 'period' and its applicability on 'type of boats'. Several studies have shown the positive impacts of SFB in terms of reduction in fishing effort and short-term stock replenishments of major marine fish species (Vivekandnan *et al*, 2010; Thomas and Dineshbabu, 2014). Further, SFB is proven to improve the inter-sectoral catch distribution in favour of artisanal fishermen, as the closure is more or less in alignment with the spawning and recruitment of species like sardines and mackerals which form the backbone of the traditional sector (Joe, 2008). Though conclusive evidence on the impact of SFB in improving long-term sustainability of stocks is yet to come, it continues to hold promise as one of the important fishery management measures that has stood the test of time in India.

Spatial controls have been another set of fishing regulations that are widely being used to restrict unsustainable and destructive fishing activities in the seas. Spatial zoning is one such measure used across states to designate specific zones in the coastal waters within which use of certain types of fishing vessels/gears/practices are restricted or prohibited. Zoning as a practiced in India targets two major outcomes: (i) to minimize excessive damage of marine biota through destructive fishing methods (eg: bottom trawling) in the in-shore waters and (ii) to maintain inter-sectoral distribution of fish catch by reserving in-shore areas for traditional / artisanal fishermen. The zones are specified either based on the distance from shore or in terms of depth of water. In general, in-shore areas for a distance of 5-10 km are reserved for artisanal fishermen who do not use any mechanized fishing activities or vessels beyond certain specified tonnage/engine power (Figure 2). However, such access restrictions are not revised from time to time based on the changes in fishing technology and practices, thereby losing relevance over time. For instance, the inboard motorized vessels used for ring seine operations in the Kerala dn elsewhere are often comparable with mechanized boats in terms of catch volumes thus violating the basic objectives of the policy.

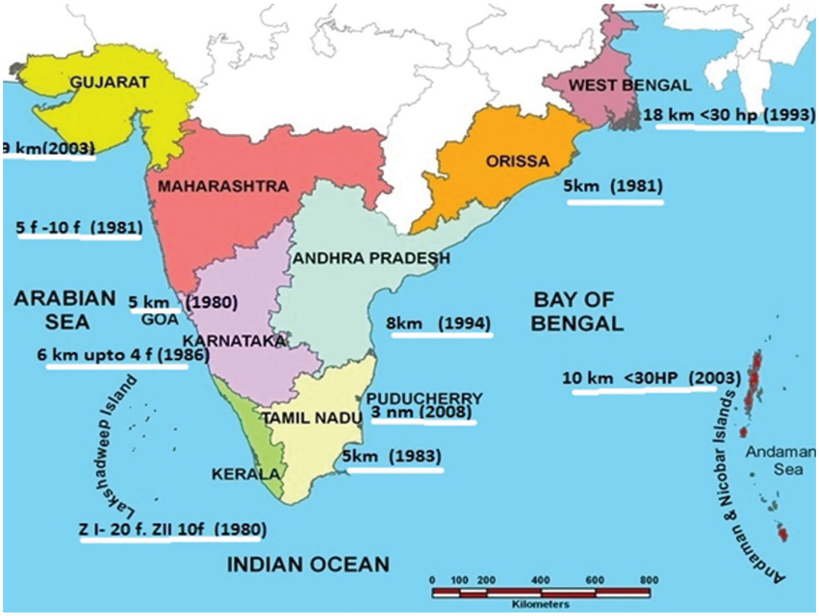

Figure 2. An illustration of spatial zoning wherein in-shore areas are reserved for artisanal fishing in India's territorial waters (Source: Parappurathu and Ramachandran, 2017)

Controlling the type/level of inputs/ fishing efforts are also hailed as a practical solution to regulate excessive exploitation of oceanic resources. The main tools presently being used include blanket ban of certain types of destructive fishing gears, mesh-size regulations, hook-size controls, turtle exclusion devices (TED), ban of fish aggregating devices (FADs) and so on. Gear restrictions are mainly targeted to minimize juvenile fishing to allow fishes to mature. However, these restrictions have largely been rendered insufficient due to poor enforcement mechanisms as well as the difficulty to judge maturity of fishes just based on body sizes. With this realization, the Kerala government notified the minimum legal sizes of 58 species of fishes/shellfishes in 2015 based on technical inputs from CMFRI, Kochi. This is first of its kind of output-based regulation to have introduced under the MFRA framework of any maritime state so far. However, the effectiveness of this measure also depends on the level of enforcement that the state can achieve within economically viable limits.

Sui generis, community-based regulatory systems

Along with formal and institutional regulatory mechanisms, a number of *sui generis* regulatory and co-management systems have co-existed in various parts of coastal India. Most of these informal, community-based governance models have evolved over time and have limited administrative jurisdictions in the concerned locales. These traditional management systems have proved to be highly dynamic by continuously adapting to changing technological paradigms and emerging challenges, retaining their relevance even now. Some such widely documented cases include the *padu* system being followed in parts of Kerala and Tamil Nadu (Lobe and Berkes, 2004); *Kadakodi* system in northern Kerala (Ramachandran and Sathiadhas, 2006); traditional *panchayat* system along the Coromandel Coast of Tamil Nadu (Bavinck, 2001) and alternate-day fishing systems in Gulf of Mannar and Palk Bay areas. The primary concerns of all these systems are resource conservation and sustainable fishery management with community control of access rights and regulations of certain kinds of harmful fishing practices. Access rights are generally determined by collective decisions based on accepted set of criteria and norms within the community. For instance, in case of *padu* system, access to designated fishing grounds is limited to members of a specific caste group in the locality based on a lottery system for harvest site allocation. The *kadakkody* system is much more elaborate with executive and legislative functions, and acts as a regulator of resources, protector of livelihoods and a mediator of social conflicts (Baiju, 2011). The *panchayat* system along the Coromandel Coast is a similar community-based governance system that regulates access and usage of fishing resources, besides discharging conflict resolution among community members. However, none of the above systems are officially recognized and continue to function as parallel systems of governance with little legal sanctity.

Conclusions

This chapter throws light on the various regulatory provisions and policies for sustainable development of India's capture fishery sector. The chapter discusses in detail the access-based, temporal, spatial, input/effort-based and output/catch-based approaches for regulating fishing effort so that the resources are exploited at optimum level. Further, the chapter also undertakes a critical appraisal of the various above provisions as enforced under the purview of MFRAs of maritime states as well as other sui-generis modes of regulations and their limitations. The chapter underscores the fact that, though sectarian interests and lack of institutional will has held back regulatory consolidation of the sector so far, fast depletion of natural resource base in the region warrants joint action propelled by farsighted vision, common interests and shared responsibilities.

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CHAPTER 38

Co-management Paradigm and Sociological Issues in Fishery Management Regime in the Indian Context : A Perspective on Re-invigoration

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There is a query which often becomes prominent and conspicuous, while speaking about the present fishery management system prevailing in a developing country like India. Do the fishery management regime and legal aspects in the Indian context require a reinvigoration? The answer for the question is in a way 'yes' and 'no' to be exact. It is likely to be a debatable issue highlighting both affirmative and negative sides in the strict literal sense. Rather than exploring the intricacies of the meaning of 're-invigoration' with a surgical postmortem approach, this paper is a simple and subtle effort on addressing the sociological issues by harnessing the paradigm of co-management ultimately for augmenting the fishery management perspective in the Indian context. It is a truth that, in the scenario of Indian Fisheries Management regime, the 'questions' are very tough and timid, but answers are so simple and known to everyone, though the impediment is the practical implementation part. The open access regime prevailing in the harvesting of marine fishery resources in our country warrants stronger emphasis on invoking technological innovations as well as management paradigms that reconcile livelihood issues with concerns on resource conservation. It is a truth that, innovations do not emerge in a socio-political vacuum. Definitely it is the extent of partnership between the research and the client system that decides the fate of any technology in terms of its adoption or rejection. Judicious and rational utilization of common property resources for sustainable development without endangering the environment is possible through community participation. For more than 6 million fishers and fish farmers, fisheries are a source of livelihood in India. Fisheries sector has recorded faster growth as compared to the agricultural sector in all the decades and is contributing in a significant way to the economic growth of the nation. The vast Exclusive Economic Zone of 2.02 million sq. km of ocean under the possession of India is more than two third of its land area. Marine fishing has been considered a primary livelihood option since time immemorial, for the occupants of the coastal belts of the country. The marine fishery resources of India include a coastline of 8129 km with numerous creeks and saline water areas, an Exclusive Economic Zone (EEZ) of 2.02 million km^2 which are suitable for capture as well as culture fisheries.

The data from CMFRI reveals that, the total marine fish landings from the mainland of India during the year 2015 were estimated as 3.40 million tonnes registering a 5.3% decline compared to 3.59 million tonnes in 2014 (CMFRI, 2016). About 3 million people are employed in the primary, secondary and tertiary sector of marine fisheries which provides livelihood security to about 18 to 20 million people (Sathiadhas, 2007). Fisheries development is a state subject in India, but, centre promotes fisheries development through state level programme planning and implementation units. The development plans for the fisheries sector have been aiming at fish production and promoting export. Though India is blessed with vast and varied fishery resources with great potential in both coastal and inland areas, fisheries production is showing a depleting trend which is adversely affecting the livelihood of fishers and making a large population vulnerable. Being the open access resource, stock assessment and irreplenishable nature of abundance in stock, conflicts of various types become the part and parcel of the fisheries system in the country. For addressing the livelihood issue, government introduced regulatory mechanisms such as gear selectivity, seasonal area closures and regulations that control the fishing effort and catching. This is the 'top down government driven management approach' through legislation. However, government managed models of management have proved to be unsuccessful as indicated by poor compliance of action and regulations resulting in crisis and adverse affects on the livelihood of fishers.

Undoubtedly, the task of managing fisheries is very complex; however, new strategies like Community-Based Fisheries Management (CBFM) which take a more regional and integrated management approach, can be more productive than past centralized management methods. CBFM achieves such productivity by combining scientific research with community involvement and Local Ecological Knowledge (LEK) to create monitoring programs specific to local areas. What does CBFM do? Actually, CBFM moves the focus of ocean resource management to individual areas/fishing communities, rather than managing fisheries on a coast wide scale. Currently fisheries are managed in many areas by a centralized or blanket method administered by a top-down approach from external managers. This approach has little involvement of the local people that are mostly affected by the managed resource. By empowering local interests, as in CBFM, local relationships may be accentuated that, large scale management strategies might not include. These older management methods also predominantly focus on "single species modeling" while newer forms of management, such as CBFM, incorporate much more of an ecosystem based management approach. CBFM proposes that resource users (fisherman) and resource communities (coastal communities), should have the primary role in deciding how the resources of that community/area are managed. "Fishermen and coastal communities, being the most dependent on coastal and marine resources, should have a large role in deciding how these resources should be managed. This idea ûts within an emerging understanding that management decisions of all sorts are often best made at the most local level possible." (Graham, *et al,* 2001)

It is a truth that, while CBFM focuses on giving primary responsibility to the local community, it is important to note that CBFM cannot take place in every scenario. It takes willingness, cooperation, involvement, and flexibility from community members to work together for the collective good. It is important that all stakeholders consider their decisions as they apply to the whole community and the health of the coastal resources. This collective responsibility for the long term well being of the natural resources depends on a type of responsible self governance, dictated not by the achievement of maximum profits or harvest, but instead by promoting a stewardship and conservation ethic. CBFM seeks the conservation and preservation of ecosystem health, combined with the sustainable use of these local resources as seen fit by the community members.

Points of focus for CBFM

Distinctly speaking, CBFM is a uniquely applied and flexible management strategy specific for every situation. It depends on open, ongoing communication within the whole community. It utilizes the large knowledge base of fishermen who already have most of the tools for good local monitoring and research. It also requires patience, working toward long term rather than short term goals. It removes the competitive spirit out of the fisheries and focuses the community on working for sustainability.

There are a few complications also in CBFM. There are many hurdles to address when implementing new management approaches such as community based fisheries management. Procedures that are necessary for legitimacy and credit among the scientific community and higher management, can pose a barrier for fisherman who lack the quantitative "hard data" about their observations. This has limited the amount of information that fisherman feel they can bring to the table, because fishermen's knowledge is largely qualitative. Many factors dictate the feasibility and productivity involved in integrating CBFM into specific communities. Some factors include: size of the population in that community, societal values, socioeconomic relations, scale of the fishing being done (industrial vs. inshore or artisanal fisheries), large economic incentives, different management techniques required for highly mobile species, limited funding for CBFM organizations, and governmental willingness in allowing more control to come from communities. All of these factors and many more can affect whether an idea for CBFM even gets off the ground. These complications often can bring about competitions and even conflicts. Let's have a look into the glimpses of different types of fisheries conflicts.

Conflicts in Capture Fisheries Sector: (Marine & Inland fisheries)

With regard to conflicts in capture fisheries sector, there are marine and inland fisheries sectors to be considered. In marine sector, each country has their jurisdiction up to 200Nm towards sea. In India concept of Exclusive Economic Zone (EEZ) enacted during 1997. In dealing with management, protection and proper utilisation of living marine resources several conflicts has been raised.

Conflicts between India and neighbouring countries: Certain examples

- Primarily arises from fishermen's violations of national jurisdiction while in the pursuit of fish. Fishermen are lacking navigational devices which can forewarn fisherman from trespassing their jurisdiction.
- Political problem between India-Pakistan and Tamil problem causing tensions between India-Sri Lanka.
- Fishermen in Okha in Gujarat accidentally trespassing Indian jurisdiction being caught by Pak navy patrols.
- Fishermen in Rameshwaram in T.N. being caught by Sri Lankan navy.
- Conflicts over marine fisheries India and Bangladesh are rather rare.

Inter-state conflicts: Some typical examples

Generally inter-state conflicts occur mainly between southwestern states and south eastern states. (Goa, Tamil Nadu, Karnataka, Kerala.) It essentially is because of differential fishing ban period during monsoon. There is no demarked boundary between states in the marine region. (Each state has their jurisdiction up to 12 nm towards sea)

Conflicts between fishermen using two levels of technology

- Large scale industrial fishing vessel and small scale fishing vessel.
- Inshore and deep sea fishing vessel.
- Trawlers and Purse-seiners.

Today there seems to be change in the direction of conflicts.

Regional conflicts between fishermen

- Between fishermen from one state to the other.
- Between fishermen from one harbour to the other.

Conflicts between fishermen and industries: Example: Mangalore coast is conspicuously noted for conflicts of fisherfolk with industries.

Inland Fisheries: accounted the conflicts in reservoir fisheries and riverine fisheries.

Culture Fisheries Sector (Aquaculture)

Social conflicts and aquaculture

- Growth of carp culture has led to the conversion of paddy fields to fish ponds.
- Affected poor people who depend on their staple food (cereal).
- Government of A.P. imposed a tax on water use for aquaculture.
- Shrimp farmer and village people.
- Effect of dykes.
- Effect of ponds around creeks.
- Salinisation problem

Conflicts between the shrimp farmers and fishermen

The shrimp farms do not provide access to the beach for traditional fishermen who have to reach the sea from the village.

A typology of fishery conflicts

In most fisheries, there appears to be little space available to increase long-term sustainable fishery benefits simply by increasing production. The fishery policy tools are generally limited to

1) Increasing the efficiency of harvesting and of management
2) Making allocation (distributing) decisions, particularly determining who has the privilege of access to the fish available for capture.

Despite superficial appearances of chaos, the wide range of fishery conflicts (of both the efficiency and allocation varieties) can be organized into a relatively small number of categories, under for inter-related headings.

(1) Fishery Jurisdiction: Involving fundamental conflicts over the who 'owns' the fishery, who controls, access to it, has is the optimal form of fishery management, and what should be the role played by governments in the fishery system.

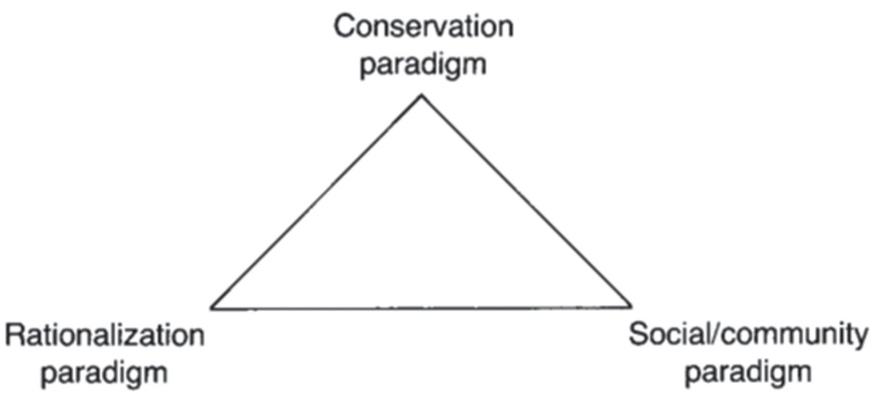
(2) Management mechanisms: concerning relatively short-term issues arising in the development and implementation of fishery management plans, typically involving fishers/ governments in the fishery system.

(3) Internal allocation: involving conflicts arising within the specific fishery system, between different user groups and rear types, as well as between fishers, processors and other players.

(4) External allocation: incorporating the wide range of conflicts arising between internal fishery players and outsiders, including foreign fleets, aquaculturists, non-fish industries (such as tourism and forestry) and indeed the public at large.

Conflicting fishery paradigms:

While the above typology categorizes fishery conflicts, the real roots of the conflicts in the underlying systematic differences in priorities pursued by the various fisheries players are to be given prime consideration. For example, everyone wants their fishery to be efficient, but the real meaning of this pleasant-sounding goal depends entirely on the desired objectives which in turn vary widely with the philosophy and ideology of the fishery players.



The conflicts and wars related to the rights over the use of land and water have been important sociological issues throughout recorded history. Although many of us are probably more aware of wars fought over religious freedom, political ideologies and social issues, conflicts over fishing rights and resources are just as common, if less reported. Since the Exclusive Economic Zones (EEZ) were established in the 1970s, disputes have become more frequent and more violent than ever before. Due to the establishment of EEZs, access to the world's oceans has been radically reorganized and the access rights of foreign fishing vessels have been curtailed. Negotiations, international fisheries agreements (such as those between European and African countries), and recourse to an international tribunal have sometimes succeeded in resolving conflicts.

Similarly, the conflict between Philippines and China is essentially due to over-access to territorial waters. Thousands of Indonesian fishers have been incarcerated as a result of illegal fishing in Australian waters. While sovereignty issues are generally at the root of such conflicts, they are also the manifestations of competition for access to fish stocks, in coastal waters as much as on the high seas. In addition, the use of flags of convenience serves to exacerbate the problem. The country where a boat is registered does not necessarily identify its country of origin, and this loophole enables fishing companies to flout international fishing and labor conventions with impunity.

Reinvigoration of Fishery Management Regime with a Paradigm shift in fisheries governance

In the Indian context, it would be vital for a reinvigoration of fishery management regime, with a paradigm shift in governance of fisheries which enables resource users (communities and fishers) and stakeholders' participation at all levels as effective partners in the management process. Management regimes as remedy cover Partnerships, Co-operation, Leasing (Aquaculture) and Co-management paradigms.

Partnership and co-operation through Fisheries co-operatives and Self Help Groups mobilized in marine fisheries sector do play a vital role in sustainable fisheries management. (Vipinkumar, 2012, 2017). Leasing essentially occurs with regard to aquaculture sector. Let's have a look into the policy and programmes for aquaculture development in India.

The registration of open water body farms and government leasing determines the appropriate areas for Mariculture activity, allocating the rights to use the resource and evaluation of environmental impacts based on certain principles to be considered to frame the Mariculture policy. (Mohamed and Kripa, 2010)

1. Common Property use conflicts: Policy guided by: Use of open water bodies for navigation and fishing should not be hindered by Mariculture. Similarly, Mariculture activities in open water bodies should not cause disturbances to other users. Permitted Mariculture by the state should be afforded complete protection of structure and stock kept in the open water bodies.
2. Carrying capacity: Open water bodies have limits to biological productions and such limits should be defined by the state in consultation with research institutions.
3. Environmental Protection: The polluter pays principle enacted by the CAAI should be applicable to pen water bodies so as to minimise environmental impacts. Pre and Post EIA (Environmental Impact Assessment) is mandatory.
4. Conservation: Aquatic ecosystems are very sensitive to changes caused by human activities and hence all activities should take into consideration conservation of aquatic biodiversity.
5. Zonation: Since Mariculture in open water bodies is diverse and region specific, states have to draw-up zonation plans in GIS formats with the help of research institutions. Creation of Mariculture parks would be of amble scope and are to be encouraged.

Co-management and Partnership Paradigms

In Asia pacific region, there are adequate success stories where the alternative models have been able to take care of all the parameters of sustainability. One of such fisheries management approaches, as an alternative to the top down government management approach is 'co-management'. This is a partnership arrangement in which the community of local resource users (fishers), government and other stakeholders share the responsibility and authority for the management of fisheries through consultations and negotiations as regards to their roles, responsibilities and rights resulting in development of effective partnerships. This ensures sustainability of the resources as well as improving the livelihood of fishers.

Co-management for Addressing Sociological Issues in Fisheries

Fisheries co-management is defined as an arrangement where responsibility for resource management is shared between the government and user groups (Nielson *et al*, 2004). It is considered to be one solution to the growing problems of fishery resource over-exploitation. If the marine fishery management regime is both to be effective and legitimate, introducing a co-management arrangement, which can be defined as a dynamic partnership using the capacity and interest of user-groups complemented by the ability of the fisheries administration to provide enabling legislation? Co-management is also a mean to reorganizing the fisheries management system. Co-management is - from this perspective - an institutional process of integrating and reallocating management responsibilities and competence (legal power) among participants by sharing the costs deriving from fisheries management with the users. Fisheries co-management is based on the following hypothesis. The involvement and participation of user-groups create incentives for cooperation in order to formulate and implement more efficient, equal and sustainable management schemes which would benefit all parties.

In the meantime, Co-management provides some sense of ownership to the fish resources, which makes the user groups far more responsible for obtaining long-term sustainability of the fish resources. It might also be more cost-efficient in terms of administration. Enforcement than centralized systems, but administration costs may increase in a co-management system, as the process may be rather time consuming, involving several interest groups.

Fisheries Co-management is often referred to as relations between fishermen and the national administration including fisheries research institutions, mainly concerning regulation methods, quota allocation and stock assessment. However, co-management can also be perceived in relation to market activities, whereby relations between fishermen and buyers come in focus. As market dynamics become more important to fishing activities, it can be expected that coordination of market performance and fisheries management measures will be increasingly important.

Co-management is a set of institutional and organizational arrangements (rights and rules), which determine how the fisheries administration and user-groups cooperate. A co-management arrangement is not a static legal structure of rights and rules, but a dynamic process of creating new institutional structures. A co-management institution can therefore be designed as an entirely new institution or can be based on already established institutional structures. The latter might often be the case in fisheries, where co-management institutions usually evolve as incremental user-group involvement in certain management tasks. The devolution of authority to manage the fisheries, away from the fisheries administration to user-groups, may be one of the most difficult tasks of co-management. On the one hand, the fisheries administration may be reluctant to relinquish their authority, or portions of it, and are often opposed to decentralization. On the other hand, user-groups may neither have the aspiration nor the capabilities to undertake enhanced fisheries management responsibilities.

The major advantages of approaching fisheries management as a bottom-up process versus the traditional centralized top-down system may be a high degree of acceptability and compliance with regulation measures, due to the participation of user-groups in the decision-making and implementation process. Once user groups are involved in the decision making and implementation of fisheries management, a spectrum of co-management arrangements can be identified. The figures illustrate the various types of institutional set-up for different co-management arrangements.

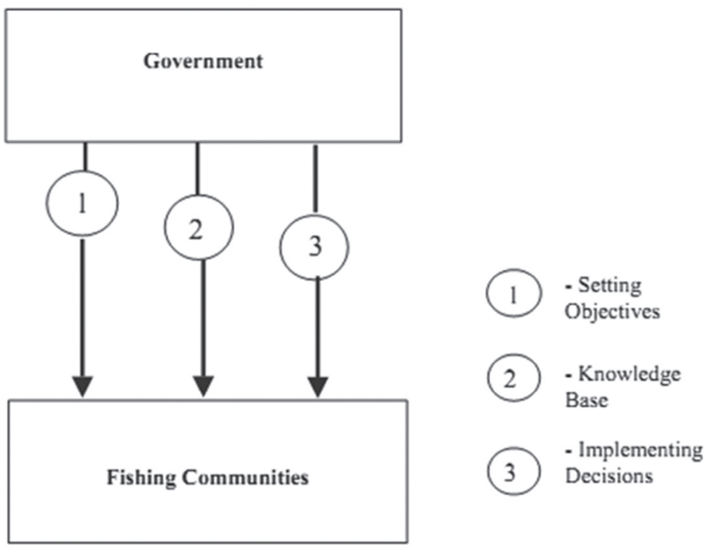


Fig. 1. Modern fisheries management

In the instructive type, it can be observed that, there is only minimal exchange of information between government and users. This type of co-management regime is only different from centralized management in the sense that the mechanisms exist for dialogue with users, but the process itself tends to be government informing users on the decisions they plan to make.

Co-management can be an innovative change to the modern ûsheries management approach as it implies a power sharing arrangement between government and ûshing communities to undertake ûshery management. However, the practical adaptation by governments of the co-management approach has most often been limited to involving ûshing communities in the implementation process—an 'instrumental co-management' approach.

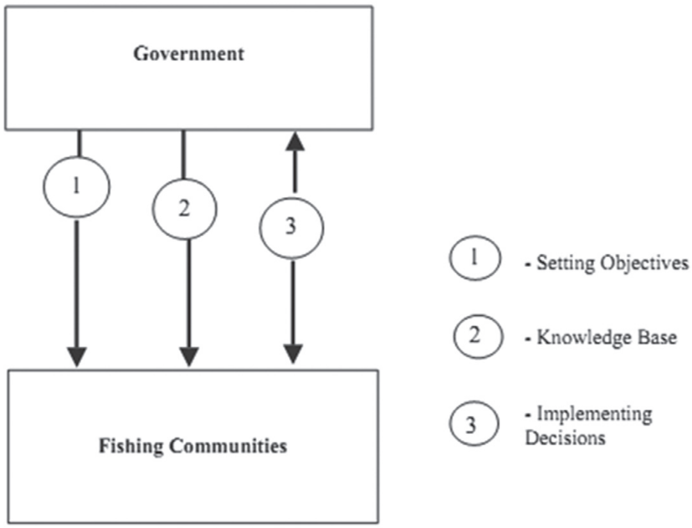


Fig. 2. Instrumental co-management

The Socio-economic considerations are likely to play a more prominent role within an empowering co-management arrangement. Empowerment of ûshing communities is a mechanism to give the people within the ûshing communities a chance to inûuence their own future in order to cope with the impact from globalization; competing use of freshwater and coastal environments; and other ûsheries related issues.

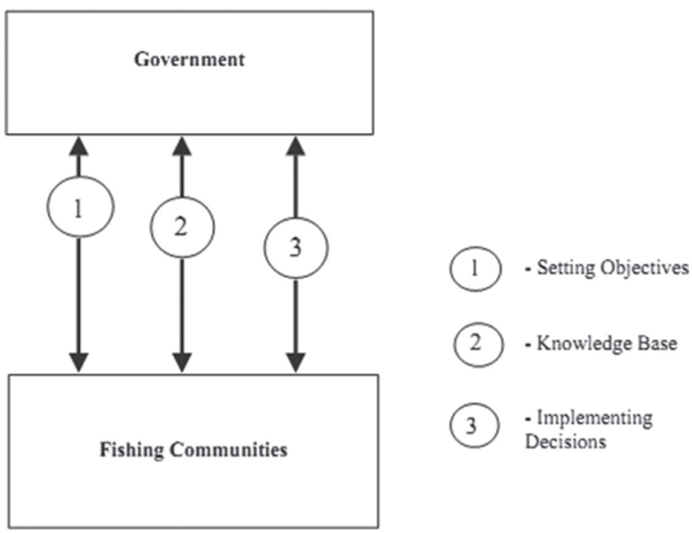


Fig. 3. Empowering fisheries co-management

The empowering co-management approach is a demanding concept, as it requires:

- A rethink of the logic for management and subsequently a change in the knowledge base for management.
- A major restructuring of the institutional and organisational arrangements supporting management.
- A substantial change in attitudes from both governments and ûshing communities towards their role in such arrangements.
- Aspiration from ûshing communities and government to proceed along this avenue.
- Capacity building at several levels both within government and ûshing communities.

Co-management for Fisheries Conservation and Livelihood

- Competitive Fishing needs to be replaced by cooperative fishing to avoid depletion and ultimate extinction of several varieties of our marine flora and fauna.
- Fishery resources are renewable but not inexhaustible.
- Cooperative fishing minimizes capital investment vis-à-vis cost of production, sustainability of resources and maximizes the earnings and profit.
- Cooperative marketing enhances the efficiency of distribution channel and enhances the earnings of real producers.

Common property: Management issues

- Common property means, no one is having ownership: hence no –management
- The literature on property rights identifies different ideal analytical types of property rights regimes:
- State property: with sole government jurisdiction and centralized regulatory controls;
- Private property: with privatization of rights through the establishment of individual or Company- held ownership.

Fisheries Co- management: Theoretical Framework

- Co- management is a new alternative management approach with a human face.
- Co-management is an effective process for the collective governance of common property resources.
- Co-operative management or co-management of fisheries can be defined as a partnership arrangement in which the community of local resource users (fishers), government, other stakeholders (boat owners, fish traders, boat builders, business people, etc.) and external agents (non-governmental organizations (NGOs), academic and research institutions) share the responsibility and authority for the management of the fishery.

- The substance of sharing of responsibility and authority will be negotiated between community members and government and be within the boundaries of government policy.
- The term 'community' can have several meanings. Community can be defined geographically by political or resource boundaries or socially as a community of individuals with common interests.

A community is not necessarily a village, and a village is not necessarily a community. Care should also be taken not to assume that a community is a homogeneous unit, as there will often be different interests in a community, based on gender, class, ethnic and economic variations.

Co-management should be viewed not as a single strategy to solve all problems of fisheries management, but rather as a process of resource management, maturing, adjusting and adapting to changing conditions over time. A healthy co-management process will change over time in response to changes in the level of trust, credibility, legitimacy and success of the partners and the whole co-management arrangement.

- Co-management is also called participatory, joint, stakeholder, multi-party or collaborative management.
- Co-management sharing and decentralization. It attempts to overcome the distrust, corruption, involves aspects of democratization, social empowerment, power fragmentation and inefficiency of existing fisheries management arrangements through collaboration
- Partnerships, roles and responsibilities are pursued, strengthened and redefined at different times in the co-management process, depending on the needs and opportunities
- The process may include formal and or informal organizations of fishers and other stakeholders.
- Fisheries co-management can be classified into five broad types according to the roles government and fishers play (Sen and Nielsen, 1996):

(1) *Instructive:* There is only minimal exchange of information between government and fishers. This type of co-management regime is only different from centralized management in the sense that the mechanisms exist for dialogue with users, but the process itself tends to be government informing fishers on the decisions they plan to make.

(2) *Consultative:* Mechanisms exist for government to consult with fishers but all decisions are taken by government.

(3) *Cooperative:* This type of co-management is where government and fishers cooperate together as equal partners in decision-making.

(4) *Advisory:* Fishers advise government of decisions to be taken and government endorses these decisions.

(5) *Informative:* Government has delegated authority to make decisions to fisher groups who are responsible for informing government of these decisions.

The equity and social justice in fisheries management is sought through co-management. Equity and social justice are brought about through empowerment and active participation in the planning and implementation of fisheries co-management. The mutuality of interests and the sharing of responsibility among and between partners will help to narrow the distance between resource managers and fishers, bringing about closer compatibility of the objectives of management.

A Case study in Indian context on Co-management

There has been an interesting sharing of ideas in SAMUDRA *Report* on the experiences and principles of co-management. All over the world, fisher communities are trying desperately to safeguard their access to fish resources, while, at the same time, being driven to catch more in order to keep afloat. The fishers of the Saurashtra coast of Gujarat, one of the foremost fish-producing States of India, are no exception, as a result of the study undertaken on "The Impact of Development on Human Population Dynamics and the Ecosystem" in three locations of the west coast of India, with the help of a grant from the McArthur Foundation.

A study location was the large fishing harbour town of Veraval in Gujarat. The findings of the study were rather revealing, not only regarding the nature of the decline of the overcapitalized trawl fishery, but also the poor environmental and social indicators in a place that had a booming fishery for over 25 years through the 1980s and 1990s. In the community feedback workshops held in 2005, people were also taken aback by the findings of the study for a while and they were aware that their fishery was on the downswing, they felt challenged to realize that a large number of the children of the community were not in school, that there was a fall in the female sex ratio, and that there was a rise in the levels of morbidity and demands for dowry at marriages. As a community that is basically business-oriented and with a desire to simultaneously claim progress, they found themselves in a prisoner's dilemma. A challenge of seeking a way out by the project authorities made them interact with them on a longer-term basis.

The fishery in the area is a trawl fishery along a 40-km coastline between the two fishing harbours of Veraval and Mangrol, which account for a third of the fish catches of Gujarat. There is also a vibrant *hodi* fishery of fiberglass-reinforced plastic (FRP) beach-landing craft, interspersed with the trawlers. Authorities got intensively involved in the fishing harbour/community of Mangrol as the community has traditionally been well organized. They were also fortunate to get a local team that the local community agreed to host. In preparation for the work, an intensive training programme was organized for the team. There were also four representatives from Mangrol and Veraval, selected by the community, who participated in the programme. They actually represented the trawl fishery.

Initiating change

Project authorities did not initially mind this fact as it was this sector that they thought had to be involved in initiating any change in resource management. The boat owners were intensely involved in the training programme and, during the subsequent period, they turned out to be the main agents of change in the community. Besides developing an analysis of the fisheries crisis, they were most intrigued by the connections made to the fall in the female sex ratio, the number of school-age dropouts, the high morbidity rates, and the extensive pollution of water bodies, all in a context where the communities were well organized but totally in the hands of men. The inputs on gender analysis and the patriarchal development paradigm helped them to see the negative side of male-dominated communities, where women have no voice, and, as a consequence, the issues of potable water, sanitation and health receive no priority. In fact, the community organizations had seen to it that entry into the trawl fishery was limited to members of the same caste. Yet just as these caste organizations camouflaged disparities in the community, they were unable to manage the manner in which investments were made in the fishery, which, in turn, aggravated the growing disparities.

On the one hand, the fishery in the area has been kept afloat by, State subsidies on diesel and, on the other, by the opening up of export markets and the development of *surimi* plants. It is otherwise an extremely inefficiently run trawl fishery, which has also contributed to the massive pollution in the harbours. But the government has gradually begun to be less lenient on the diesel subsidies, certain export consignments have been rejected by some importing countries, and the government has begun giving greater importance to developing coastal resources other than fisheries. The fishing communities, therefore, needed to get their act together and think differently about their fishery and its future if they did continue to consider the fishery as a means of livelihood.

A couple of strategies to tackle this problem were developed at the training programme, and a plan was drawn up to set up a coastal area managing council in a year as well as push for co-management of the fisheries. The first step was to develop a general awareness in the community about the inter-relationships among the ocean, the land and the people so that people understand how these affect one another. This was done at several levels through all kinds of community programmes but the strategy in the first year was to:

- develop a forum for women where they could discuss and understand these issues and, at the same time, create a collective to gradually represent their cause and themselves in the community organization (*samaj*);
- create an awareness among the youth and children about the coast and oceans; and
- widen the understanding of the fishers themselves regarding coastal-area issues, and relate these to their fisheries-management possibilities. For this, efforts were made to also include the elected representatives of the municipality in discussions related to these issues so that they would be taken into consideration in town planning.

The interesting results were from an active group of women fish vendors who pressured the municipality and the fisheries department for a better fish market, while another group made a detailed study of the community's problems relating to water, sanitation and attendant infrastructure, which was presented to the members of the *samaj*. In both these cases, the community's men were very responsive and open to the idea that women could also be part of the co-management process.

The discussions on co-management were done separately for the fishing sectors, the community organizations and the women so that all of them could understand the issues and felt free to raise doubts and make suggestions from the point of view of their own sectors. It was clear that there were several areas of conflict.

After the deliberations and discussions, all the representatives got together to discuss the possibility of a larger plan and who would finally meet the government and scientists to make the proposed presentation on co-management. Importantly, it was the first time that women and men from various sectors, caste and religious groupings had got together to discuss coastal and fisheries issues.

An Expert Consultation on Fisheries and Area Co-management was held in Ahmedabad, the capital of Gujarat, supported by the Fish Code Programme of the Food and Agriculture Organization of the United Nations (FAO), where the State's entire fisheries department was present, together with scientists from the Central Marine Fisheries Institute (CMFRI), the Central Institute of Fisheries Technology (CIFT) and the Fisheries Survey of India (FSI), as well as trader, processor and non-governmental organizations (NGOs) and the Marine Products Export Development Authority (MPEDA).

Community leaders first presented their ideas on co-management, which included both the need for fisheries management and coastal-area management, and articulated why they thought that this was a viable option in their particular context. They requested the government to create a framework of legislation for co-management, where both their rights to the coastal resources and the responsibilities of the government and the various stakeholders would be clearly defined. Subsequently, the experts responded, and a group discussion followed on the action that could be taken.

A heated discussion between the trawl-boat owners, the scientists and the government officials had even the women chipping in, but unfortunately the *hodi* owners remained silent. The importance of this process has to do with the fact that co-management was proposed by the community representatives from a shore-based fisheries perspective and not a fishing perspective alone. This was possible because of the data available and the focus on the fishery as a means of livelihood that has to be sustained. But this is not an easy process and it still has to be operationalized. The bank on the tremendous amount of goodwill shown by all the stakeholders, indicates that the stakes in actually managing the fisheries are high.

A case study of *Kadakkody* in Kerala: Conflict resolution though Sui-generis co-management:

Kadakkody: A linguistic aberration of the Malayalam word '*Kadal-kodathy*' literally meaning 'Sea Court'. It has legislative, executive and judiciary roles to play in the Araya and Dheevara communities of Hindu fishermen belonging to Kasargod district of Kerala. *Kadakkodies* make their presence felt strongly in four regions like Kasargod, Kizhoor, Kottikkulam and Bakkalam. It plays as a community based fisheries management institution. Though functional only in a few pockets of north Malabar coast of Kerala, these age old institutions are similar to many of the Caste Panchayats prevalent in rural India. (Ramchandran, 2004).

Constitution of *kadakkody*: Each *kadakkody* is an adjunct to the temple of the fishermen community in each village. Ruling deity in all these temples is *Kurumba Bhagavathy* who is considered the most worshipped 'mother goddess' (Devi) among Hindu fisherfolk. Each *kadakkody* has three distict bodies (1) *Sthanikan* (the permanently authorized), (2) *kadavanmar/Sahayiees* (temple messengers or assistant priest and they represent the police) and (3) Temple committee.

Sthanikans are composed for 4 separate constitutional groups namely *Karnavanmar* (4 members) Achanmar (6 members), *Kodakaran* (1 member) and *Anthithiriyan* (2 members). *Karanavanmar* are the high priests of the temple and they act as magistrates belonging to 4 *illams* such as *chempillam, kachillam, karillam and ponnillam. Achanmar* are six in number and are basically oracles (*velichapadan*) at the temple and are assistant magistrates. *Kadavanmar* are the messengers/ police. Temple committee is a democratically elected body. The factors determining the legitimacy of *kadakkody* are divine authority, social embeddedness, systematic procedures and behavioural norms, participatory and transparent process, quick and fair judgements, functional diversity, shared sense of pride etc.

Typological differentiation of 2 forms of co-management: (Ramchandran, 2004)

Charactieristics	***Sui- generis* form of CBCRM**	**State induced/supported CBCRM**
Self Governance	High	Low
Basis of legitimacy	Divine	Legislative
Group of homogeneity	High	Medium
Compliance	High	Low
Social embeddedness	High	Low
Adaptability	High	Low
Ethos	Cosmic	Livelihood
Norms	Uncodified	Codified
Management agenda	Inclusive	Exclusive
Epistemological base	Socially embedded	Mostly officiated version
Ownership over means of production	Exclusive	Inclusive

The best method of co-management is to follow the Code of conduct for responsible fisheries. Let's look into the issues pertaining to responsible fisheries management.

Govt. Regulations for conservation

1. Regulation of fishing effort for exploiting the resources, particularly the shrimp resource which is a single critical resource and centre of most of the controversies and conflicts in the country
2. Restriction of number of fishing gears which exploit the juvenile phase in the backwaters, estuaries and shallow inshore were through licensing
3. Mesh size regulation
4. Minimum legal length for capture and
5. Closed seasons and areas

Fishing methods & Resource conservation

1. Introduction and popularization of synthetic fishing gear materials
2. Introduction of trawling in mid 1950s
3. Improvement in efficiency and diversification of trawls, purse seines, gillnets and lines, for mechanised sector,
4. Continuous improvement in size, endurance, installed engine power, winch capacities, fish-hold, freshwater and fuel capacities of mechanised vessels to enable multi-day fishing, since mid 1980s
5. Adoption of modern technologies such as eco sounder and GPS on a wider scale over the last decade, enabling precision fishing
6. Motorization of traditional fishing craft in 1980s and expansion of fishing grounds of traditional motorized fleet
7. Introduction of ring seine in commercial fishing in 1986
8. Introduction of mini trawling in mid-1987 and its subsequent proliferation
9. Introduction of ring seine with inboard engine and purse line haulers in 1999 and continuous increase in numbers

Mesh size Regulations

- A common measure for reducing the catch of juveniles and small sized non-target species in trawls and important step towards reducing the growth over fishing, rampant in Indian fisheries.
- Though 35 mm has been prescribed for trawl cod-end and incorporated in the MFR of Kerala, it has never been perfect.
- Mesh size for sardine/mackerel ring seines may be regulated at 22 mm or more in the bunt and main body and maximum dimension of the gear may be limited to <600 m hung length and <60 m hung depth, for all replacement constructions; length overall and engine horse power for propulsion may be limited to 20m or less and 65 hp respectively, for replacement constructions. Anchovy ring seine may be regulated at 12 mm & Engine horse power for propulsion may be limited to 25hp.

Responsible Fishing Methods and Practices

- Guidelines associated with use and development of fishing gear and practices delineated in the Code focus on (I) selective fishing gear and practices (ii)environment friendly fishing gears (iii) energy conservation in harvesting and iv) enhancement of resource (FAO 1995) The CCRF is purely voluntary. The best way to follow these codes will be adoption of co-management.
- Specific pointers from CCRF, in responsible fishing and practices, adaptable to Kerala include the following:

- Evolve regionalized consensus Code of Conduct for Responsible Fishing, in close participation with all stake holders (traditional, motorized and mechanised fishermen organizations) fisheries research organizations and fisheries managers
- Take measures to control open access by strict enforcement of a system of licenses (authorization to fish) in traditional motorized and mechanised sectors
- Develop ecosystem based fishery management regime, in collaboration with the union Government and neighboring maritime states sharing the same fishery-related marine eco system services
- Identify and delimit protected areas in marine and inland water ecosystems
- Periodically revalidate maximum sustainable yield of resources in the existing fishing grounds and determine fishing units in each category for sustainable harvesting of resources
- Take steps to remove excess capacity over a time schedule, with active stakeholder participation.
- Explore possibilities for a rights based regulated access system based on a strong inclusive cooperative movement of stakeholders with built-in transferable quota system and buy-back or rotational right of entry schemes for capacity management and optimization in the shelf fisheries, in collaboration with the Union Government and the neighboring states with confluent ecosystems and shared fishing grounds.
- Conduct periodic audit of fishing craft and gear combinations, their economics of operation and ecological impacts
- Standardize the capacities, dimensions and specifications of fishing units in each category, particularly in the mechanised and motorised sectors
- Evolve a system for marking fishing vessels and fishing gear (both traditional & mechanised)
- Maintain registry of all fishing vessels in waters under state jurisdiction with all essential details
- Evolve regulations and promote use of life saving, fire fighting and communication equipment for safety of fishermen
- Evolve regulations for mandatory survey of mechanised fishing vessels
- Promote selective fishing gear and practices
- optimum mesh size in trawl cod-ends
- Optimum hook size and shape for lines
- Square mesh windows in trawls
- Bycatch reduction devices in trawls
- Turtle excluder device in trawls

- Trawl designs with improved resource specificity
- Optimum mesh size for gill nets
- Optimum mesh size for purse seines
- Escape windows in fish and lobster traps
- Evolve an efficient Monitoring Control and Surveillance (MCS) system
- Promote effective use of Geographical Information System for fisheries management; monitoring and control of fishing effort and energy use
- Evolve an promote a package of practices for energy conservation in fish harvesting
- Evolve a mandatory programme of training and certification for non-motorized, motorized and mechanised fishermen in safe navigation responsible fishing, log keeping and reporting

Perspectives and Reinvigorating challenges ahead

Meticulous observations and experiences of various co-management implementations have revealed potentials and benefits of co-management, but also many unresolved sociological issues and problems that need to be addressed. There is still a long way to for harnessing the various co-management systems and examples of solutions to for addressing a varietal range of sociological issues and problems for reinvigorating the fishery management regime of a developing nation like India. Many of the problems and issues facing Fisheries can only be solved on a provincial, national or even international level. The resource systems on which fisheries rely are in most cases too large to be entirely within control of a few communities, and Fisheries management institutions must therefore be able to address problems of resource access and sharing on that level. The solution to this scale problem may be representation within nested systems, but this raises a new set of problems relating to mechanisms to ensure genuine representation and to avoid a new process of alienation between communities and management is initiated. Reconciling local and global agendas: International agreements on fisheries and environmental management are a special case of incongruence between scales. Means must be developed by which the governments can serve the double obligation of attending to international agreements while sharing power in setting objectives for fisheries management with the communities. Identifying a knowledge base for management, which is considered valid by stakeholders: The knowledge base for fisheries management should relate to the objectives of management and be considered valid by the stakeholders? A co-management system must develop mechanisms to reconcile formal scientific knowledge and fishers' knowledge about their resource system in a way that maintains scientific validity and wide acceptance. There are no shortcuts and easy solutions to this problem. One approach may be to identify indicators of the status of the resource system that are both supported by science and reflects fishers' observations. Developing approaches to manage conflicts between resource users who have acquired exclusion rights to a resource through the co-management process and those who are excluded: There is a need to understand the mechanisms and actual reasons behind the alienation process of the different user groups in order to manage these conflicts. Developing appropriate approaches for empowering local communities to participate in the setting of management objectives through institutional reform: This may require substantial change in the way that management authorities function to provide fisheries management services and changes in perceptions of stakeholders on the roles of fisheries management agencies. These issues must be addressed in practice in practical experiments with co-management. It is however important that, such experiments are documented and the experiences communicated to others who may be in the process of establishing or developing co-management arrangements. It is therefore imperative in the Indian context that, attempts to harness co-management are associated with independent research to document and disseminate the experiences for addressing sociological conflicts and emerging issues for an effective reinvigoration of the fishery management regime.

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CHAPTER

39

Fishery Biology In Conservation- How Successful are we?

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HISTORY OF MARINE CONSERVATION

Coastal human communities have been exploiting the sea as a source of food from time immemorial. Ancient communities have long had codes of conduct, largely undocumented, for judicial use of these bioresources. Some such practices are evident from the understanding of traditions of ancient hunter gatherer communities which have persisted up to modern times. The stone age Onge tribe of the Andamans practice discretion while hunting dugong and sea turtle and never harvest in excess. Examples of fishery conservation are several in Indian history. The edicts of Emporer Ashoka lays out rules for fishing. The fifth inscription of Delhi Shivliks bans activities of fishing and fish selling from Ashadh full moon to Paush full moon, on the days of Pusyankshtr in Paush, full moon, a day before full moon, no moon and both Pratipadas. Fishing permits find mention in Arthashastra of Kutilya as a means to conserve fishery resources.

In the Western world, early commercial fishing was unregulated and fishery resources considered as "commons" and open to exploitation by all. The first fishery conservation law dates back to 1816 when the Lofoten Fishery law was enacted in Norway allocating fishing fields to fishers in the famed cod fishery of the region. In 1936 the first Overfishing Conference was held in London to address issues plaguing North European fisheries. Unprecedented reduction in the population of whales prompted the International Convention for Regulation in Whaling to be held in 1946 after which the International Whaling Commission was set up. An integral part of the Convention is a legally binding Schedule which lays out specific measures that the IWC has collectively decided are necessary in order to regulate whaling and conserve whale stocks. In 1957 Ray Beverton and Sidney Holt, considered the fathers of fishery sciences, came up with their model to predict and manage fisheries, which went on to become the seminal work on which fisheries management the world over was based. The field of fish population dynamics saw rapid evolvement since then. From the 1960s to 1980s fisheries models evolved in a deterministic setting, with advances in age-structured models (Gulland, Pope, Doubleday), surplus production models (Pella, Tomlin-son, Schnute, Fletcher, Hilborn), growth models, bioeconomic models (C. Clark) and management control models (Hilborn, Walters) . A major advance in the 1990s was the development of Bayesian and time series methods. Currently, theory allows realistic modeling of age- and size-structured populations, migratory populations and harvesting strategies. These models routinely incorporate measurement error, process error (stochasticity) and time variation (Quinn, 2003).

In 1982 the United Nations Convention on the Laws of the Seas (UNCLOS) was adopted and the world saw the establishment of Exclusive Economic Zones (EEZs) and territorial waters whereby nations could stake claims to fisheries in their regions for an extent of 200 nautical miles. Signatory nations drafted and augmented legislation to safeguard their fishery resources. In 1995, the FAO published the Code of Conduct for Responsible Fisheries (UNCCRF) for member countries of the United Nations to further augment their legislation on. "After two decades since its adoption, the Code continues to be a reference framework for national and international efforts, including in the formulation of policies and other legal and institutional frameworks and instruments, to ensure sustainable fishing and production of aquatic living resources in harmony with the environment" (FAO, 2018). In 1996 the Marine Stewardship Council (MSC), an independent non-profit organisation, was founded to set standards in sustainable fisheries. Marine products from fisheries assessed and certified by MSC as sustainable are entitled to bear their certification trademark, which gives them an edge in competitive customer preference. In 2004 the United Nations General Assembly issued a Resolution on Fisheries that prepared for further development of international fisheries management law which seeks to regulate new fisheries on the high seas which do not fall under the jurisdiction of individual nations. In 2005, the UBC Fisheries Centre at the University of British Columbia reviewed the performance of the worlds' major fishing nations against the mandate of the UNCCRF. The Aquaculture Stewardship Council was set up in 2010 on similar lines as MSC to cater to sustainable aquaculture enterprises the world over.

APPROACHES FOR CONSERVATION

The recent approaches for conservation are based on taxa or ecological structures and/or processes or a combination of both. Conservation measures based on **taxa** focus on a single species or a group of similar species. Eg: The conservation of swordfishes or sharks or whales or sea turtles. Most fisheries management practices fall under this category. Measures based on **ecological structures or processes** are concerned with the conservation of these within a well defined geographical limit. Eg: Conservation through Marine Protected Areas or No Take Zones. Some measures are a combination of both categories Eg: Coastal Zone Management or ECOPATH modelling.

Most conservation efforts are based on scientific management tools which in turn rely on sound biological data and derivations from the same for framing the management recommendations.

Fishery management related inputs

Perpetuation of the resource through judicious exploitation is the aim of all conservation efforts through fisheries management strategies. The inputs required to successfully formulate management constructs for any given fishery bioresource falls under the category of fishery inputs and biological inputs.

Fishery inputs used are as follows:

- Gear-wise annual catch and effort
- Gear-wise age structure of target species
- Fishing grounds and season
- Value of catch at different stages of marketing
- Census of fishers, vessels and gears

Biological inputs used are as follows:

- Age structure of stock (through analysis of length frequency distributions, tagging experiments, counting rings on hard parts such as otoliths, scales, vertebrae or fin rays)
- Age and maturity criteria (SSD, MSM, SCM, L_m)
- Length weight relationship
- Growth rate (VBGF, L_c, L_∞)
- Maturity stages and Fecundity
- Sex ratio
- Natural mortality (M)
- Fishing mortality (F)
- Spawning behaviour and grounds
- Nursery grounds
- Foraging grounds
- Migratory habits
- Food and feeding habits

(Annala & Eayrs, 2010; Roff and Zacharias, 2011)

Some approaches employed for stock assessment

Stock assessment of fisheries is done for the purpose of fisheries management using the above inputs and a few basic constructs which have been explained below:

Catch per Unit Effort: It is the simplest approach used for resource stock assessment. It is based on the measurement of landings of a stock and the fishing effort expended to land that stock. At the beginning of a fishery, the CPUE will be high which will lower as the fishery progresses. In a well managed fishery, the CPUEs decline is arrested and stabilizes at the sustainable level as the fishery matures. In poorly managed fisheries the CPUE continues to decline until the fishery finally collapses. Computations of maximum sustainable yield using Surplus Production Models and models such as Schaefer Fox model are based on CPUE. Errors and inaccuracies using these models often occurs due to the inherent problems of using CPUE. Primarily, all errors in recording or assessing catch data reflects in the CPUE. It also does not account for technological advances or changes in fishing methods which renders comparisons over time periods erroneous. A practical difficultly in fishery management is that often by the time meaningful usage of CPUE is used for assessing a fishery, it is already in decline.

Maximum Sustainable Yield (MSY) is theoretically the maximum catch that can be harvested from a species stock which will not result in long term depletion of the resource. It is based on the assumption that the fished species produces surplus numbers in each spawning than required for maintaining the population size and that this surplus stock can be exploited at a maximum level without damaging the stock. When a population is small, the number of recruits to a fishery is limited and hence the yield small. However for an intermediate sized population, the number of reproducing individuals are large which produces surplus recruits which in turn can be harvested. At half the carrying capacity of the population, reproductive rate is at maximum. In modern fisheries the MSY averages about 30% of the unexploited population size for most fish species. The concept of MSY was the main method relied upon by fishery managers ranging from international bodies such as IWC and ICNAF to individual countries from the 1950s to 1970s after which the deficiencies of using this simple concept as a mainstay became apparent in the form of collapsed fisheries. Inspite of its deficiencies MSY was drafted into the United Nations Laws of the Seas (UNCLOS) in 1982 making it a management goal for most countries which incorporated it into national and international legal instruments. The MSY concept is now refined and combined with Virtual Population Analysis by most fishery managers who use the FAO recommended **FAO-ICLARM Stock Assessment Tool (FISAT)** for fish stock assessment. Fishery biology parameters such as L_∞, K, t_0, M, F, Z are all part of this routine and form the basis on which the prediction models such as Thompson and Bell model are used. Correct and accurate estimation of these parameters is vital to computations through population dynamics models. The MSY is not a fixed figure for a given population and must be reassessed periodically as recruitment patterns are subject to variation influenced by factors such as environmental fluctuations and fishing effort.

Another practice employed in stock assessment is to calculate the **Spawning Potential Ratio (SPR)** which compares the spawning ability of a fished population to that of an unfished population. The spawning ability is then compared with mortality to estimate the stock. To assess the spawning ability, the number of eggs produced per recruit in the population until caught is divided by the number of eggs produced by the recruit over its entire lifetime if not caught. This SPR when calculated using biomass or weight of adult stock or biomass of mature females or biomass of eggs produced is called **Spawning Stock Biomass (SSB).** When SSB is calculated per recruit the it is called **Spawning Stock Biomass Per Recruit (SSBR).** SPR also employs age determination of the recruit through length-weight constructs or through measurement of otoliths.

Ecosystem Based Fisheries Management (EBFM)

The difficulties and deficiencies caused by basing fisheries management on single species or groups brought a paradigm shift in approach to EBFM during the 1990s. A more holistic approach which included ecological relationships between the species, their physical environment and human influence was applied to fisheries management. Fishery biology, prey predator relationships, environmental stressors, oceanic parameters, prevalent diseases, all these were accounted for in the EBFM models.

Ecopath

The main software in use for EBFM is called Ecopath which was developed by Jeffrey Polovina of NOAA and further modified by Carl Walters and Villy Christensen at the UBC Fisheries Centre of the University of British Columbia to include Ecosim and Ecospace.

"**Ecopath with Ecosim** (EwE) is a free ecological/ecosystem modeling software suite. EwE has three main components: *Ecopath* – a static, mass-balanced snapshot of the system; *Ecosim* – a time dynamic simulation module for policy exploration; and *Ecospace* – a spatial and temporal dynamic module primarily designed for exploring impact and placement of protected areas. The Ecopath software package can be used to evaluate ecosystem effects of fishing; explore management policy options;analyze impact and placement of marine protected areas, predict movement and accumulation of contaminants and tracers (Ecotracer). model effect of environmental changes and facilitate end-to-end model construction.... The latest release of Ecopath with Ecosim is version 6.5, released in July 2016." (Ecopath.org, 2018)

An Ecopath model describes the trophic interactions, synthesizing ecological and fisheries data of an ecosystem at a given time. These models account for the biomass of each functional group of species, their diet composition, production per unit of biomass (P/B, per year), consumption per unit of biomass (Q/B, per year), mortality rate from natural causes (M) and fishing (F), accumulation of biomass and net migration rate (all rates being annual). The principle behind this ecosystem modelling approach is that, on a yearly basis, biomass and energy in an ecosystem are conserved.

Ecopath models rely on the truism that:

Production = biomass accumulation + fisheries catch + mortality due to predation + other mortality + loss to adjacent systems.

Groups are linked through predators consuming prey, where:

Consumption = production + non-assimilated food + respiration (Lopez,2016)

FISHERY MANAGEMENT STRATEGIES

These are broadly categorised into the restrictions that are based on inputs that go into the fishing operations ie input controls and restrictions on the outcome of the fishing operations ie output controls.

Input Controls:

- Restriction on fishing types Eg: Dynamite fishing
- Restriction on gear types: Eg: Limits on fish traps, number of poles or lines per fisherman
- Prescribing minimum mesh sizes and promoting certain designs such as diamond shaped cod end meshes.
- Limiting the average potential catch of a vessel in the fleet by imposing restrictions on the vessel or crew size, number of units of gear deployed, electronic gear and other physical "inputs"
- Prohibiting bait. Eg: Ban on light fishing
- Restricting the number of simultaneous fishing vessels Eg: Ban on pair or bull trawling
- Limiting a vessel's average operational intensity per unit time at sea, limiting average time at sea

- Restricting area or season of fishing Eg: Marine Protected Areas and trawling ban seasons.

***All fishery management methods currently employed in India are based on input controls*.**

Output controls

These catch limit methods have been employed in other countries and are especially useful where there are stocks in decline.

- **Total Allowable Catch (TAC):** Limit set on the total weight or numbers of bioresorces harvested in a given period of time. Eg: Pacific halibut fishery
- **Individual Fishing Quota (IFQ):** A certain portion of the TAC is allocated to individual vessels or fishers based on initial qualifying criteria. Eg: Alaska halibut, sablefish, wreckfish fisheries in USA.
- **Individual Vessel Quota (IVQ):** TAC is divided amongst all vessels registered in a fishery and not amongst individuals. Eg: Canadian and Norwegian fisheries.

(Roff and Zacharias, 2011)

CONSERVATION MEASURES PRACTISED IN INDIA

Legal instruments for conservation of marine fishery resources

The maritime states of India have so far enacted 23 legislations to conserve fishery resources in India. The oldest piece of legislation is the Indian Fisheries Act, 1897 and the latest is the Lakshadweep Marine Fishing Regulation Rules, 2004.

Major provisions covered by these **Marine Fisheries Regulation Acts** and other notifications and ordinances are:

- Mandatory registration of motorised and mechanised crafts
- Demarcation of areas for fishing for different types of crafts
- Prescription of mesh size for various gears
- Proclamation of closed seasons
- Ban on certain types of fishing
- Ban on bait fishing
- Restriction of fishing time
- Restriction of landing of catch to certain ports
- Inclusion of turtle excluder devices in certain regions

Other major laws concerning fisheries, marine organisms and habitats are **The Wildlife (Protection) Act, 1972 (IWPA)** and its seven amendments and the **Coastal Zone Regulation notification (1991, 1994, 1996)** under **The Environment (Protection) Act, 1986**. Under the various Schedules of the IWPA, 03 endangered species of marine mammals, 06 reptiles, 10 fishes, 24 molluscs, all sea cucumbers, corals and sponges are accorded protection from hunting, trade and exploitation as trophies. Specific areas are demarcated as wildlife protected areas and all species within such areas are also given protection under this Act. Coastal areas upto 500 m from the High Tide Line are protected under the CRZ notification by classifying them into four zones with various constructional and usage restrictions being imposed on each.

Protection is also accorded to marine organisms through international treaties such as the **Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES)** under which more than 5000 species of animals and 29000 species of plants are listed under three Appendices as per the level of threat to their existence and the degree of control on their trade. India, since 1976, is one of the 183 parties who are signatories of this treaty. 11 species of Indian elasmobranchs are listed under Appendix I and II of CITES. The **Convention on Migratory Species (CMS)** aims to protect species such as whales which perform transboundary migrations and require the cooperation of different countries whose territorial waters they occupy or pass through from time to time.

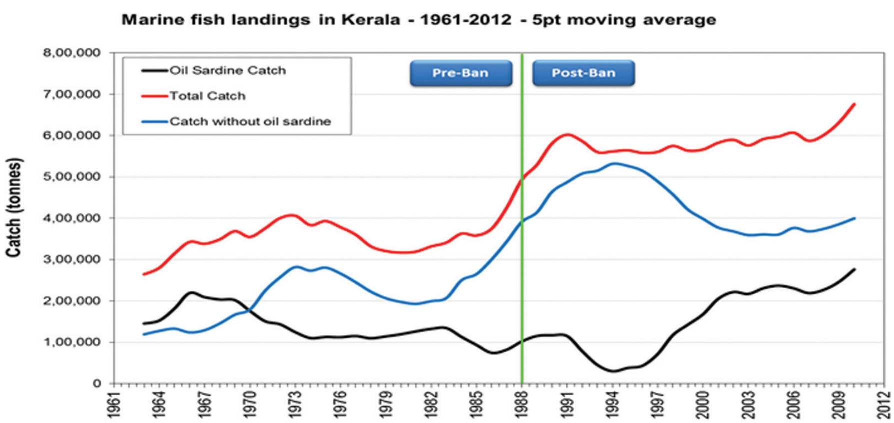
Monsoon Trawling Ban

All maritime states of India have effected a period of conservation of marine bioresources through a seasonal fishing ban which ranges from 45 to 61 days. The ban aims at alleviating fishing pressure from spawners and fingerlings and thus avoid growth and recruitment overfishing, allowing an opportunity for replenishment of stocks. The monsoon is chosen as the timing for the ban as several fish and crustacean species record peak spawning periods during this season. Following are the dates from which the ban is currently followed in the various states:

- Gujarat: Since past two decades no fishing from 10 June to 15 August.
- Maharashtra: 1 June to Nariyal Poornima (2nd week of August)
- Goa: 4 June to 25 July
- Karnataka: 1 June to 31 July
- Kerala : 15 June to 31 July
- East coast maritime states : Since 1999, 46 days closure from 16 April to 31 May
- Andaman & Nicobar Islands: 15 April to 31 May for bottom trawlers & shark fishing vessels; 1 May to 30 September for sea shell fishing

These dates are generally adhered to though small changes may be made in any given state year to year.

A fact sheet published by the Ministry of Environment, Forests and Climate Change and Deutsche Gesellschaft für Internationale Zusammenarbeit (2016) states that about 10.36 million fishing hours are reduced due to Seasonal Fishing Ban (SFB), equivalent to 408,000 tonnes of CO_2 emitted with a savings of 156.58 million litres of diesel. In 2014, an amount of Rs 8.3 billion (US$ 137m) was saved on diesel during fishing ban. The Factsheet stated that the estimated economic value (based on landing price) of the incremental growth of fish attained due to a fishing ban of 45-60 days was a total of 1.07 billion (US$ 18m) in the five states. The transaction cost, which includes information to fishermen and enforcement of the ban amounts to Rs 45.78 million (US$ 0.76m) in the five states. Estimated net social benefit due to SFB in five states was Rs 1.09 million (US $18,167). However, The Committee To Evaluate Fish Wealth/ Impact Of Trawl Ban Along Kerala Coast in its concluding remarks stated that as per the analysis of the effects of the trawling ban in Kerala, "The economic analysis indicates that in value terms the benefit of the trawl ban was present only up to the year 2000, after which there has been a decline in real value of the fisheries and ultimately incomes to fishermen in spite of increase in nominal value. The growth rate analysis also clearly indicates that growth rate in the mechanized sector is negative after the year 2000, and the benefit of the trawl ban was not sustained after 2000."



(Mohamed et al., 2014)

Both the MoEFCC & GIZ and the above Committee recommend the extension of the trawling ban period for better and more effective results. In addition to the trawling ban, CMFRI and MoEFCC & GIZ also recommend other management measures, such as an minimum legal size, ecosystem-based approach, marine protected areas including no-take zones, regulated entry, catch quotas and certification.

Minimum Legal Size:

The menace of juvenile fishery has led to the fast depletion of marine bioresources along the Indian coasts. Fishes that have not yet had the opportunity to spawn are termed as juveniles. These are mainly fished in the seasons following spawning by using small mesh sized nets. Majority of the juvenile fish catch sent to fish meal plants. Though fetching immediate gains it is a great economic loss for fishers as small sized fishes fetch low price as compared to what price it would have fetched had the fishes been allowed to grow to larger sizes. It is also ecologically damaging as stocks do not get replenished leading to growth overfishing. It leads to decline and collapse of stocks especially vulnerable low growth rate, low fecundity or restricted distribution species. Juveniles also form the bulk of low value byecatch (LVB) especially that of trawlers. 25 species of finfihes, 16 species of crustaceans and 15 of molluscs recorded as LVB in India, several of which are juveniles of commercially valuable species. In addition, low value byecatch species are prey items of larger commercially valuable fishes. (Ganga *et al*., 2014)

Imposition of a **Minimum Legal Size** (MLS) of fish species landed through mesh size selectivity is a management tool being used to combat the menace of juvenile fishery of commercially important fish species. MLS has been computed and imposed for 40 commercial finfish, 13 crustacean and 05 molluscan species in Kerala through an ordinance. The Government of Kerala implemented MLS initially for 14 fishes on 24.07.2015 notified vide GO (P) no.40/15/ F &PD and recently on 17.05.2017 another 44 species were added and updated vide GO(P) No.11/2017 F&PD. For detection of violations random species-wise subsample of the catch (about 25-50 numbers) are measured and considered as a violation if more than 50% of the catch sample is composed of fishes at or below the prescribed MLS. In this manner some mitigation is envisaged for curbing the growth overfishing which entails uncontrolled exploitation of juvenile fishes for fish meal plants resulting in resource depletion and economic loss. Imposition of MLS ensures that juveniles survive to grow and spawn, controls the numbers and sizes of fish landed, maximizes marketing and economic benefits and promotes the aesthetic value of fishes. Fishery biologists determine the maturity stages of the fishes through long term observation of catches for arriving at the MLS. Various criteria employed for computing the MLS of fishes are:

CRITERIA	LOGIC	EXAMPLES
Size at sexual differentiation into male and female (SSD)	Used to prevent juvenile exploitation and female growth overfishing in those stocks which are very abundant, have high reproductive potential and whose biomasses are not affected by high fishing pressure.	*Sardinella longiceps* *Trichiurus lepturus* *Megalapsis cordyla*
Minimum size at maturity or size of smallest mature fish (MSM)	Used to prevent growth overfishing in stocks which are moderately resilient to fishing pressure	*Scomberomorus commerson Nemipterus randalli Saurida tumbil Coryphaena hippurus*
Size at first maturity or size at which 50% of the fishes are mature (SFM)	Used to prevent growth overfishing completely and recruitment overfishing partially. Can be used in situations where the stock is depleted or rebuilding.	*Scomberomorus guttatus* *Rachycentron canadum*
Size at complete maturity or size at which 100% of the fish are mature (SCM)	Can be used to prevent recruitment overfishing by capping maximum legal size of capture. Seasonally applicable to fishes which grow to large size and exhibit slow growth rates. (Sunil Mohamed et al., 2014)	Sharks, rays and skates
Weight at First Maturity (WFM)	Used exclusively for lobsters. Notified by MPEDA	Lobsters

Fishing of juveniles can be avoided through strictly following the net and mesh size regulations prescribed by the Trawl Ban Committee Report (2014). The success of MLS as a management measure encourages similar provisions to be adopted by other maritime states in India. A recent preliminary study of the impact of MLS found that income of fishers has come down temporarily by 3 % in the mechanised sector and 2.1% in the motorised sector but increased by 0.4% in the non-motorised sector due to MLS adoption. Violation of rules by fishers belonging to other states where there is no legislation on catch landed is a major constraint experienced by fishers adopting MLS (Meharoof, 2018).

Marine Protected Areas

Designating coastal and marine areas of high diversity as protected areas and placing them under special laws is a management strategy which has been employed with foresight and expectations as has been done for their counterparts in the terrestrial realm in India. MPAs are classified into three major types based on the degree of protection and management practices in play. **Multiuse MPAs** are those where sustainable use of the resources of the MPA by humans is permitted. In **No-take MPAs** no kinds of human usage of the resources is permitted. **Marine Biosphere Reserves** are a combination of both with fully protected core areas, an intermediate buffer area and outer transition zone where activities such as sustainable fisheries is permitted. Other areas where conservation is mooted but not declared as national parks or sanctuaries by law are **Ecologically and Biologically Sensitive Areas (EBSAs)** and **Community Reserves.**

In India 6.79% of the total coastline under MPAs. 25 MPAs are located in mainland India covering an extant of 8214 sq.km which is 4.92% of the total Protected Areas. Maximum number (105) of MPAs are located in in the Andaman & Nicobar islands and one in Lakshadweep (Sivakumar, 2013). The areas were chosen based on the richness in biodiversity, existence of fragile habitats or areas important to the stages in the lifecycle of flagship marine species. Major MPAs in India area Gulf of Kachch Marine National Park, Gulf of Mannar Marine Biospehere Reserve, Sunderbans National Park, Bhitarkanika Wildlife Sanctuary and Coringa Wildlife Sanctuary. 25 wetlands have been designated as Ramsar wetlands by GOI.

17,795 species of marine organisms are conserved in these MPAs which amounts to a biodiversity of about 6.75% of the worlds known marine species (Sivakumar et al., 2013). While the primary aim of the MPAs is to provide sanctuary to marine organisms and preserve fragile ecosystems such as mangroves and coral reefs, parts of these are also of tourism value.

Though at present conservation methods are based on input controls in India where fisheries management is a complex effort owing to the multispecies multi-gear nature of its fisheries, the future will bring in more focus to include output controls as well as ecosystem based fisheries management. The input control measures introduced so far have limitations as enforcement remains a major consideration and desired outcomes fall short of targets due to noncompliance by some, rather than failure of the method adopted. Synchronicity in the application of the management measures for example the timing of the monsoon fishing ban along the west coast or the adoption of MLS by all maritime states will be essential for their success in totality. Overcapacity of the fleet and unsustainable practices resulting in declining trends in conventional commercial resources will ultimately result in situations where stringent management measures will have to be adopted. The current effort of managers is to avoid such situations by maintaining the fisheries at its peak in a sustainable manner.

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CHAPTER 40

Effect of Environmental Variations on Fishery Biology and Fisheries: The Indian Oil Sardine - A Case Study

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Introduction

The marine ecosystem is dynamic and the variations several abiotic and biotic factors directly and indirectly affect the fish stocks and their population structure. Spawning and recruitment success is to a large extent linked to these environmental variations. It is well known that resources occupy a particular habitat because of their preference to the environmental variables prevalent there and also due the availability of food. We have large shoal forming small pelagic fishes like the sardines and anchovies and the deep water large pelagic and demersals occupying the marine ecosystem from the upper pelagic zone to the benthic realms. Fishing is one of the major activities directly impacting the fish stocks and fishery records show several cases of overfishing leading to stock collapses. Definitely, fishery management tools have supported revival of several of these stocks but have failed to do so in few others. Almost equally important in inducing the biological changes that control maturation, spawning and recruitment are the some ocean atmospheric processes which change inter-annually in the tropics.

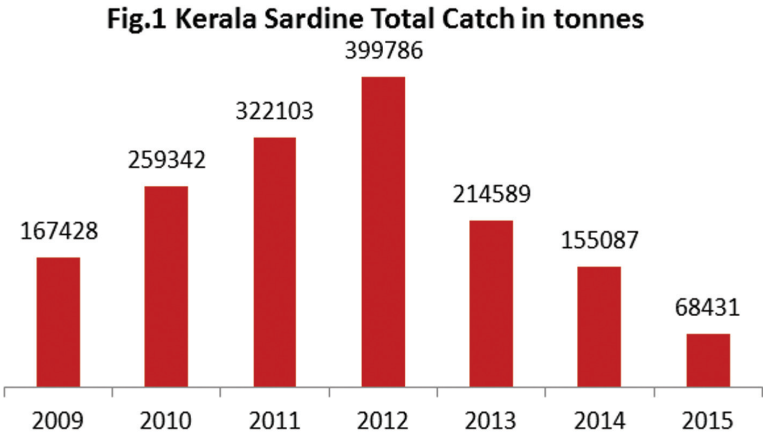
Globally, small pelagics serve as important forage species and support several higher tropic level fisheries. They also support coastal livelihoods and form an important source of low cost and high quality protein to several villagers. In addition to this, they serve as raw material to several post-harvest processing units which prepare canned, smoked and dried products regularly.

One common factor among most of these fishes is their ability to increase in biomass to very high levels and then suddenly decline and collapse. They revive slowly taking to 2 to more than 6 to 8 years depending upon the reason and the intensity of overfishing. All these changes in biomass, like the sudden increase and the low levels are mainly controlled by environmental factors. A recent study on the decline in sardine fishery along the Kerala coast revealed the role played by several abiotic and biotic ecological parameters which determine the recruitment success. The importance of environmental variables on recruitment success is detailed below through the recent investigations on sardine fishery.

Sardine Fishery of Kerala

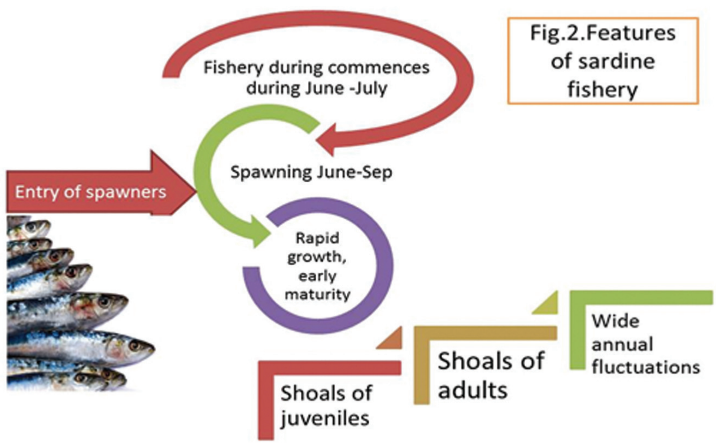
The Indian oil sardine is a small shoal forming pelagic fish which is caught mainly by seines. Historic records describing the fish and fisheries of Kerala indicate that in the year 1320 Odoric has commented that there were plenty of fishes in coastal waters in Kerala, and this is presumed to be a one of the earliest reference to sardines. Apart from being used as food, sardins were used for oil extraction which was exported from Cochin port. Historic records show that sardine fishery has collapsed several till during the last two centuries and **Day (1865)** has observed the ill effects of unrestricted in diminished catches in later years. He also thought that oil sardine "*occasionally forsake their haunts for several consecutive seasons, returning again in enormous quantities*"

The sardine catch in 2012 was 3.9 lakh tonnes which was the highest during the last two centuries and then the decline started. The catch declined by 46 % in 2013 (catch 2.1 lakh tonnes), then by 61% in 2014 (catch-1.6 lakh tonnes) and by 82% in 2015 reaching 68431 tonnes (Fig.1). Within a span of 5 years, the state witnessed the highest catch and lowest catch. During the period 1960 to 2015, the sardine stock has reached the collapsed status only once (1994.)



Most often, before a fishery collapse, over fishing of the stocks leading to imbalance in the population structure and biomass has been known to occur. As per an estimate of CMFRI based on 2005 to 2007 data the MSY of sardine along Kerala coast, is 2.3 lakhs tonnes. So during the period 2011 and 2012, the stock was fished above the MSY by harvesting nearly 2.5 lakh tonnes.

Excessive harvest of juveniles: About 16,040 tonnes of juveniles (less than 10cm) forming 4% of the total catch were harvested in 2012 and about 4802 tonnes in 2013. This would have affected the spawning biomass of 2013, 2014 and 2015. (16,040 tonnes of less than 10cm sardine would have contributed to a biomass of 5,61,400 tonnes at 30% mortality in the subsequent years . Similarly if the 4802 tonnes of juveniles were allowed to grow, it would have supported a spawning population of 1,68,070 tonnes of sardine)



The Indian oil sardine is known to move to inshore waters for spawning in large shoals. This is the time when the sardines have been fished in large quantities. After spawning, the young ones grow rapidly in the near-shore area (Fig 2). The environmental variations affect all the biological processes.

Role of Fishery dependent factors in reducing fish stocks

Usually age structure in a fish population is balanced. However, due to intense fishing pressure, either due to growth overfishing or due to recruitment overfishing, the fish stocks can be affected and in such instances they become vulnerable to adverse environmental conditions. Less than one year old sardines have always formed a major component of sardine population. However, during the period Oct 2012 to Feb 2013 about 1,17,823 tonnes of 10 to 14 cm size sardines were harvested. The large scale removal of this group also would have affected the potential spawning population of 2013 and 2014. Thus the population of sardine was affected. So by the beginning of 2013, the sardine stock off Kerala was severely affected-low biomass and less number of potential spawners. What followed after that was adverse environmental conditions, though not continuous, affected spawning and recruitment.

Environmental factors controlling sardine maturation and spawning

Upwelling and monsoon are two major ocean –atmospheric processes which are known to influence sardine maturation and spawning (Fig 3). They are known to mature by April –May and spawn from end of May to August/September. Recruitment is usually from July/August onwards.

Fig 3. Time line of reproductive phases and key environmental processes

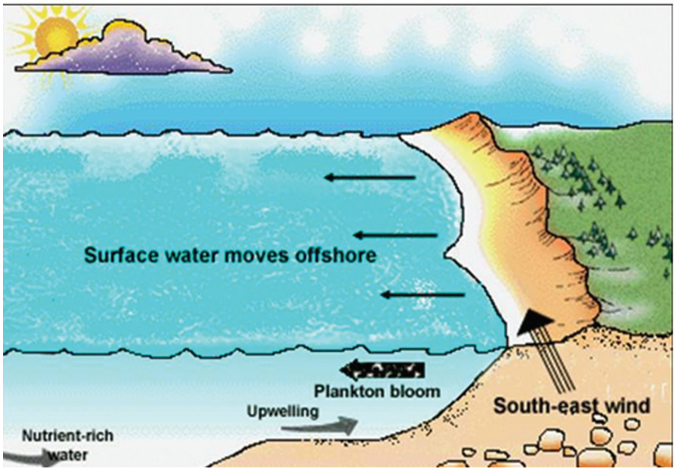
Upwelling and Recruitment

Upwelling is a process in which deep, cold water rises toward the surface. *Upwelling* occurs when winds push surface water away from the shore and are replaced by cold, nutrient-rich water that wells up from below (Fig 4) . Deep ocean water is more nutrient-rich than surface water as nutrients, dead and decaying plankton and other fish carcasses sink to the bottom. During upwelling these are brought back to the surface and these fertile systems support blooming of diatoms and zooplankton. This rich food supports growth and maturation of several fishes.

Upwelling is most common along the west coast of continents (eastern sides of ocean basins). In the Northern Hemisphere, upwelling occurs along west coasts (e.g., coasts of California, Northwest Africa, India) when winds blow from the north (causing Ekman transport of surface water away from the shore). Along the Indian west coast, upwelling is strong along Kerala coast and is known to occur in varying intensities.

Upwelling and fish maturation:

Fig.4. Schematic diagram of Upwelling



As mentioned earlier, upwelling triggers blooming of diatoms and these provide food for the maturing fishes like sardine. Along Kerala coast upwelling sets in by May -June and this suddenly increases the Gonado-Somatic Index of sardine making them ready for spawning. When there is poor upwelling, the major factors supporting gonad development like blooming of diatoms and lowering of ambient temperature does not happen and this can lead to poor maturation or delayed maturation. In 2015, upwelling was poor and maturation was affected.

Upwelling and dissolved oxygen

Upwelling can also bring in low oxygen water which can lead to hypoxic conditions. Sometimes along Kerala coast, low oxygen in upwelled waters can be seen in the sardine habitat during August –September. If the dissolved oxygen levels are below one ml /l then this has been found to affect recruitment and the fishery. In the sardine habitat along Kerala coast, the influx of upwelled waters with low oxygen (0.7 to 0.8 mg per litre) was found in the main sardine habitat during August 2013 .Low mixing of waters can cause stratification and along with hypoxic conditions cause stress to the early life stages.

Upwelling and jellyfishes

Jellyfishes are known to bloom and survive in adverse conditions. When upwelling creates low very oxygen conditions jellyfishes are not affected. Hence they also proliferate in the coastal waters. These can increase the biotic pressures on the larval and juvenile stages through predation.

Timing of upwelling

If upwelling occurs very early and if the intensity is high with low oxygen waters in the habitat, this can prevent the spawners from entering the coastal waters for spawning. In such cases, spawning may be delayed.

Monsoon-Rainfall and Recruitment

When maturation is largely influenced by upwelling, the onset and intensity of southwest monsoon has a good influence on sardine spawning and recruitment. Though there is no direct affect, the changes triggered by monsoon especially the blooming of plankton in near-shore waters supports early larval development. The high levels of phosphate, nitrate and silicate in the river runoff triggers and supports blooming of diatoms. These support the large shoals of early life stages of sardine. Similarly, there will be negative impacts when the riven runoff is high and there is no proper mixing. This can lead to stratification and adversely affect recruitment.

In 2013 there was good maturation in sardines during pre-monsoon period, but the spawning and recruitment processes were affected by the above normal rainfall during June and July. The rainfall during June and July of 2013 was 60 and 14% more than the normal.

The sardines were exposed to “stress” due to salinity stratification i.e extremely low salinity due to excessive river runoff in the surface waters and higher saline waters in the bottom.

Deficit monsoon

In 2014 there was good maturation in sardines during pre-monsoon. However, since the monsoon was deficient during June/July it delayed the spawning period. A successful spawning as in normal years was not observed in spite of good maturation. Sporadic spawning was observed from April to Sep/Oct (7 months). Though spawning was observed during third week of June it was not complete.

Excess rainfall during late monsoon

In 2014.monsoon was excess by 74% and 22% during August and September than the normal. This resulted in low saline waters and salinity stratification which affected recruitment.

Ocean Atmospheric Processes

El Nino

El Niño is the warm phase of the El Niño Southern Oscillation (commonly called ENSO) and is associated with a band of warm ocean water that develops in the central and east-central equatorial Pacific . ENSO refers to the cycle of warm and cold temperatures, as measured by sea surface temperature, SST, of the tropical central and eastern Pacific Ocean. El Niño is accompanied by high air pressure in the western Pacific and low air pressure in the eastern Pacific. The cool phase of ENSO is called “La Niña” with SST in the eastern Pacific below average and air pressures high in the El Nino affects the global climate and disrupts normal weather patterns, which as a result can lead to intense storms in some places and droughts in others. At least 26 El Niño events since 1900 have been identified, with the 1982-83, 1997–98 and 2014–16 events among the strongest on records. ENSO is the most important coupled ocean-atmosphere phenomenon to cause global climate variability on inter-annual time scales.

Multivariate ENSO Index

The **multivariate ENSO index**, abbreviated as MEI, is a method used to characterize the intensity of an El Niño Southern Oscillation (ENSO) event. Given that ENSO arises from a complex interaction of a variety of climate systems, MEI is regarded as the most comprehensive index for monitoring ENSO since it combines analysis of multiple meteorological and oceanographic components such as sea-level pressure (P), zonal (U) and meridional (V) components of the surface wind, sea surface temperature (S), surface air temperature (A), and total cloudiness fraction of the sky (C).

Impacts on ecosystems and fisheries

In Peru, the warm water and low food availability that accompany El Nino have led to decline in anchovies that make up the largest fishery on Earth. Global total capture fishery production in 2014 was 93.4 million tonnes, of which 81.5 million tonnes from marine waters and 11.9 million tonnes from inland waters. (FAO, 2016). For the first time since 1998, anchoveta was not the top-ranked species in terms of catch as it fell below Alaska Pollock.

In 2015, it was observed that upwelling was low and the sardine habitat changed considerably. There was no good maturation and spawning during 2015, consequently poor recruitment. Though maturation was observed during May/June, it was not as healthy as in previous years. Globally, 2015 has been considered as a warm year with high temperature and low food. The average seawater temperature in sardine habitat was 29.8^o C during 2015, which is nearly 1.1 deg C higher than the average observed (28.6 ^{o} C) for the last 5 years. Positive SSTA exceeding 0.6^{o}C dominated in the tropical Indian Ocean. There was a substantial warming in the tropical Indian Ocean, partially due to influences of the 2015 El Nino. The mean SST in the tropical Indian Ocean was reported to increase by 0.13-0.2^{o}C in 2015. Phytoplankton density was also low during April/May 2015 compared to the high during 2012. This low food availability in the habitat was found to affect maturation which resulted in poor recruitment.

Combined effects of overfishing and environmental stress

Thus the cumulative effect of overfishing above MSY in 2011 and 2012 including the exploitation of nearly 16,040 tonnes of juveniles in 2012 affected the sardine population/biomass. This was followed by poor recruitment in 2013 and 2014 due to environmental stress due to salinity stratification (due to excessive rains in late monsoon) and hypoxic condition (due to upwelling) in inshore sardine habitats.

Low food availability and comparatively higher temperature due to poor upwelling led to poor maturation and subsequent recruitment success. In 2015, these changes were compounded mainly by global ocean –atmospheric process like *El nino*. The various facters affecting maturation, spawning and recruitment of oil sardine is given in Table 1.

Table. 1 Factors affecting maturation, spawning and recruitment in oil sardine

	Parameter	Maturation	Spawning	Recruitment	Level of impact
1	Upwelling in April/May	Favourable			Vey strong
2	Good diatom bloom				Very strong
3	Monsoon on-start -May				Mildly strong
4	Monsoon normal				Very strong
5	Delayed monsoon		Unfavourable		Mildly strong
6	Excess rainfall (floods)				Mildly strong
7	Low oxygen in inshore waters	Unfavourable		Unfavourable	Very strong
8	*Noctiluca* /Jellyfish bloom				Mildly strong

Policy support for protecting sardine stock for revival

Sardine fishery has collapsed during last century also. To revive the stocks, Government of Madras introduced restricted legislation in Malabar and South Kananra Districts in 1943; then extended to another two years from 1945 to prohibit use of the following nets for immature sardine all throughout the year. Landing of immature oil sardine below 15 cm not exceeding a total weight of one Maund (28 maund =1 ton) was also prohibited. The legislation lapsed in 1947 due practical difficulties encountered in enforcement such as (1) lack of preventive staff all over the coast (2) lack of legislation in adjacent states

The drastic decline after 2012 affected the fishing industry very badly, especially the traditional fishermen and those fishers who had invested heavily on fishing. In a move to protect the resource, the Department restricted fishing of juveniles of fishes based on scientific advisory by CMFRI and the Minimum Legal Size (MLS) was introduced for 14 species. For sardine the MLS was 10 cm.

In almost all major sardine and anchovy fisheries, when the fishery is showing a downward trend, the scientists and administrators join together and introduce Total Allowable Catch or close the fishery for a specific period. The stocks are influenced both by overfishing and by extreme events.

CHAPTER

41

Stem Cell Culture and Potential Applications

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Stem cells are the body's "master" cells because they give rise to all other tissues, organs, and systems in the body. Each tissue within the body contains unique type of stem cells that renew and replace that particular tissue (e.g. nerve, brain, cartilage, blood) when needed, due to damage or wear and tear. Stem cells have the remarkable potential to develop into many different cell types in the body. Basically, these cells serve as a sort of repair system for the body; they can theoretically divide without limit to replenish other cells as long as the person or any other living being is still alive. When a stem cell divides, each new cell has the potential to either remain a stem cell or become another type of cell with a more specialized function, such as a muscle cell, a red blood cell, or a brain cell. The classical definition of a stem cell requires that it possess the following two properties :

Self-renewal - the ability to go through numerous cycles of cell division while maintaining the undifferentiated states

PLuripotency - the capacity to differentiate into specialized cell types. In the strictest sense, this requires stem cells to be either **totipotent** or **pluripotent** - to be able to give rise to any mature cell type, although **multipotent** or **unipotent** progenitor cells are sometimes referred to as stem cells

Totipotent cells are considered the "master" cells of the body because they contain all the genetic information needed to create all the cells of the body plus the placenta, which nourishes the embryo. Human cells have this capacity only during the first few divisions of a fertilized egg. After 3 - 4 divisions of totipotent cells, there follows a series of stages in which the cells become increasingly specialized. The next stage of division results in pluripotent cells, which are highly versatile and can give rise to any cell type except the cells of the placenta. At the next stage, cells become multipotent, meaning they can give rise to several other cell types, but those types are limited in number. An example of multipotent cells is hematopoietic cells—blood stem cells that can develop into several types of blood cells, but cannot develop into brain cells. At the end of the long chain of cell divisions that make up the embryo are "terminally differentiated" cells (cells that are considered to be permanently committed to a specific function).

Pluripotent stem cells are isolated from embryos that are a few days old. Cells from these embryos can be used to create pluripotent stem cell "lines" —cell cultures that can be grown indefinitely in the laboratory.

The two broad types of vertebrate stem cells are:

E**mbryonic stem cells** that are found in blastocysts and **Adult stem cells** that are found in adult tissues.

In a developing embryo, stem cells can differentiate into all of the specialized embryonic tissues. In adult organisms, stem cells and progenitor cells act as a repair system for the body, replenishing specialized cells, but also maintain the normal turnover of regenerative organs, such as blood, skin or intestinal tissues.

As stem cells can be grown and transformed into specialized cells with characteristics consistent with cells of various tissues such as muscles or nerves through cell culture, their use in medical therapies has been proposed. In particular, embryonic stem cell lines, autologous embryonic stem cells generated through therapeutic cloning, and highly plastic adult stem cells from the umbilical cord blood or bone marrow are considered as promising candidates.

Identifying Stem Cells

The practical definition of a stem cell is the functional definition - the ability to regenerate tissue over a lifetime. For example, the gold standard test for a bone marrow or hematopoietic stem cell (HSC) is the ability to transplant one cell and save an individual without HSCs. In this case, a stem cell must be able to produce new blood cells and immune cells over a long term, demonstrating potency. It should also be possible to isolate stem cells from the transplanted individual, which can themselves be transplanted into another individual without HSCs, demonstrating that the stem cell was able to self-renew.

Properties of stem cells can be illustrated *in vitro*, using methods such as clonogenic assays, where single cells are characterized by their ability to differentiate and self-renew. As well, stem cells can be isolated based on a distinctive set of cell surface markers. However, *in vitro* culture conditions can alter the behavior of cells, making it unclear whether the cells will behave in a similar manner *in vivo*. Considerable debate exists whether some proposed adult cell populations are truly stem cells.

Embryonic stem cell lines (ES cell lines) are cultures of cells derived from the epiblast tissue of the inner cell mass (ICM) of a blastocyst or earlier morula stage embryos. ES cells are pluripotent and during development, give rise to all derivatives of the three primary germ layers: ectoderm, endoderm and mesoderm. In other words, they can develop into each of the more than 200 cell types of the adult body when given sufficient and necessary stimulation for a specific cell type. They do not contribute to the extra-embryonic membranes or the placenta.

A human embryonic stem cell is also defined by the presence of several transcription factors and cell surface proteins. The transcription factors Oct-4, Nanog, and Sox2 form the core regulatory network that ensures the suppression of genes that lead to differentiation and the maintenance of pluripotency. The cell surface antigens most commonly used to identify hES cells are the glycolipids SSEA3 and SSEA4 and the keratan sulfate antigens Tra-1-60 and Tra-1-81. The molecular definition of a stem cell includes many more proteins and continues to be a topic of research.

ES cells, being totipotent cells, require specific signals for correct differentiation - if injected directly into the body, ES cells will differentiate into many different types of cells, causing a teratoma. Differentiating ES cells into usable cells while avoiding transplant rejection are just a few of the hurdles that embryonic stem cell researchers still face. Many nations currently have moratoria on either ES cell research or the production of new ES cell lines. Because of their combined abilities of unlimited expansion and pluripotency, embryonic stem cells remain a theoretically potential source for regenerative medicine and tissue replacement after injury or disease.

Adult stem cells

The term **adult stem cell** refers to any cell which is found in a developed organism that has two properties: the ability to divide and create another cell like itself and also divide and create a cell more differentiated than itself. Pluripotent adult stem cells are rare and generally small in number but can be found in a number of tissues including umbilical cord blood. Most adult stem cells are lineage-restricted (multipotent) and are generally referred to by their tissue origin (mesenchymal stem cell, adipose-derived stem cell, endothelial stem cell, etc.)

A great deal of adult stem cell research has focused on clarifying their capacity to divide or self-renew indefinitely and their differentiation potential. In mice, pluripotent stem cells are directly generated from adult fibroblast cultures.

While embryonic stem cell potential remains untested, adult stem cell treatments have been used for many years to treat successfully leukemia and related bone/blood cancers through bone marrow transplants. The use of adult stem cells in research and therapy is not as controversial as embryonic stem cells, because the production of adult stem cells does not require the destruction of an embryo. Consequently, more US government funding is being provided for adult stem cell research.

Lineage

To ensure self-renewal, stem cells undergo two types of cell division. Symmetric division gives rise to two identical daughter cells both endowed with stem cell properties. Asymmetric division, on the other hand, produces only one stem cell and a progenitor cell with limited self-renewal potential. Progenitors can go through several rounds of cell division before terminally differentiating into a mature cell. It is possible that the molecular distinction between symmetric and asymmetric divisions lies in differential segregation of cell membrane proteins (such as receptors) between the daughter cells. An alternative theory is that stem cells remain undifferentiated due to environmental cues in their particular niche. The signals that lead to reprogramming of cells to an embryonic-like state are also being investigated. These signal pathways include several transcription factors including the oncogene c-Myc. Initial studies indicate that transformation of mice cells with a combination of these anti-differentiation signals can reverse differentiation and may allow adult cells to become pluripotent. However, the need to transform these cells with an oncogene may prevent the use of this approach in therapy.

Applications of Stem Cells

Stems cells – whether cord blood, adult or embryonic – have numerous applications in the areas of scientific research and cell therapy. For researchers, stem cells are the key to understanding how humans develop the way they do. Hopefully, the study of stem cells will unravel the mystery of how an undifferentiated cell is able to differentiate, and will also determine what is the signal that triggers the sequence. The greater understanding, and possibly even control, of cell division and differentiation is a significant strategy in the battle against dreaded illnesses such as cancer, which is basically the continuous multiplication of abnormal cells.

The use of stem cells for the testing of new medicines is another highly-anticipated application. Although certain cells are already utilized for this purpose – cancer cells, for example, are used to tests anti-tumor drugs – testing on pluripotent cells would open up this field to a much broader number of cell types.

The third, and possibly most important, application is cell therapy, which is the use of stem cells to produce the cells and tissues required for the renewal or repair of body organs that have been damaged by debilitating and mortal diseases such as cancer, spinal cord injuries, glaucoma and Parkinson's disease.

Stem cells provide the opportunity to study the growth and differentiation of individual cells into tissues. Understanding these processes could provide insights into the causes of birth defects, genetic abnormalities, and other disease states. If normal development were better understood, it might be possible to prevent or correct some of these conditions. Stem cells could be used to produce large amounts of one cell type to test new drugs for effectiveness and chemicals for toxicity. Stem cells might be transplanted into the body to treat disease (diabetes, Parkinson's disease) or injury (e.g., spinal cord). The damaging side effects of medical treatments might be repaired with stem cell treatment. For example, cancer chemotherapy destroys immune cells in patients, decreasing their ability to fight off a broad range of diseases; correcting this adverse effect would be a major advance.

Before stem cells can be applied to human medical problems, substantial advances in basic cell biology and clinical technique are required. In addition, very challenging regulatory decisions will be required on the individually created tissue-based therapies resulting from stem cell research. Such decisions would likely be made by the Center for Biologics Evaluation and Research (CBER) of the Food and Drug Administration (FDA). The potential benefits mentioned above would be likely only after many more years of research. Technical hurdles include developing the ability to control the differentiation of stem cells into a desired cell type (like a heart or nerve cell) and to ensure that uncontrolled development, such as a cancerous tumor, does not occur. Some experiments may involve the creation of a chimera, an organism that contains two or more genetically distinct cell types, from the same species or different species. If stem cells are to be used for transplantation, the problem of immune rejection must also be overcome. It is hoped that the creation of many more embryonic stem cell lines will eventually account for all the various immunological types needed for use in tissue transplantation therapy. Others envision the eventual development of a "universal donor" type of stem cell tissue, analogous to a universal blood donor. However, if the Somatic Cell Nuclear Transfer (SCNT) technique/cloning was employed using a cell nucleus from the patient, stem cells created via this method would be genetically identical to the patient, would presumably be recognized by the patient's immune system, and thus would avoid any tissue rejection problems that could occur in other stem cell therapeutic approaches. Because of this, many scientists believe that the SCNT technique may provide the best hope of eventually treating patients using stem cells for tissue transplantation.

ES cell cultures from piscine species

Embryonic stem (ES) cells are undifferentiated cells derived from early developing embryos of animals, characterised by their capacity for self-renewal and pluripotency. These cells retain their pluripotency after long-term cultivation *in vitro* and can be induced to differentiate into a variety of cell types. When introduced into host embryo, the ES cells can participate in normal development and contribute to several tissues of the host, including cells of the germ line. These characteristics make ES cells ideal experimental systems for *in vitro* studies of embryonic cell development and differentiation and a vector for the efficient transfer of foreign DNA into the germ line of an organism. In addition, ES cells provide an attractive strategy for the preservation of biodiversity (Hong *et al*., 1996). These cells have the potential to produce any type of cell of the body and can be propagated in unlimited quantities, which led to the importance of human ES cells (hESCs) in regenerative medicine and treatment of a variety of diseases.

In spite of the discouraging situation encountered in other animal species, fish are especially suited for developing ES cell technology for two reasons *viz.*, piscine species are of considerable interest for both basic studies in molecular, cellular, and developmental biology as well as for commercial interest. As model vertebrate organisms, zebrafish and medaka are competitive with mouse for the analysis of gene functions relevant to humans. In the aquaculture activity, there is an increasing interest for incorporating new fish species for diversification. Fish have several technical advantages over other vertebrates such as high fecundity, large transparent embryos, and rapid development. Fish embryos often develop outside the mother, which is a big advantage for initiating embryonic stem cell cultures from fish compared to mouse. The starting point is the mid-blastula (MB) embryo. The first goal in developing fish ES cells was to establish conditions that supported growth of the embryonic stem cells while avoiding spontaneous differentiation. ES cell-mediated gene transfer is a promising approach for producing site mutated transgenic fish with enhanced growth rates or disease resistance, as well as for analyzing functions of fish genes (Melamed *et al.*, 2002). ES cells along with other cellular based strategies, such as primordial germ cells and nuclear transfer, allow selecting the desired transformation events before transferring the transgene to the whole animal.

Another important aspect of piscine cells is their lowest position in the ladder of evolution, which makes them suitable for xenotransplantation in mammals (Wright and Yang, 1997; Laue *et al*., 2001; Wright and Pohajdak, 2001). The islet tissue in certain teleost fish like tilapia called Brockmann bodies has been shown to restore normoglycemia on transplantation into diabetic nude mice (Wright and Pohajdak, 2001). Similarly, reversal of streptozotocin-diabetes has been achieved after transplantation of piscine islets to nude mice (Laue et al., 2001). These reports indicate potential of piscine cells for clinical applications.

To develop ES cell lines and gene targeting techniques in fish, extensive studies have been done in small model fishes such as zebrafish and medaka, because they offer the possibility of combining embryological, genetic, and molecular analysis of vertebrate development. ES-like cell lines have been established in medaka (Wakamatsu *et al*., 1994; Hong *et al*., 1996) and zebrafish (Collodi *et al*., 1992; Sun *et al*., 1995). One medaka ES-like cell line, MES1, was shown to retain a diploid karyotype and the ability to form viable chimeras (Hong *et al*., 1998).

Development of ES cell technology in model fish prompted application of feeder-free cell culture conditions to commercial species. The main objective was to improve the productivity of farmed fish by targeting genes related to commercial traits on ES cells, such as growth, or disease resistance. A technical goal was to genetically modify fish by making germline chimeras or by nuclear transfer (Bejar *et al*., 1999). The first, long-term, stable cell line from a commercial species was SaBE-1, which was derived from the marine fish gilthead seabream (Bejar *et al*., 1999). From this cell line a clonal culture was derived (SaBE-1c) that was screened for pluripotency *in vitro* and *in vivo* (Bejar *et al.*, 2002). Cells were characterized for proliferation, chromosome complement, alkaline phosphatase staining, telomerase activity, and induction of cell differentiation. Chimeric fish have been made in which all three embryonic germ layers are mosaic, but the efficiency was low in terms of survival and contribution of the donor cells (Bejar *et. al*., 2002). Long-term embryonic cell lines have been subsequently derived from species of commercial relevance in Asia. The first two were SBES1 from red seabream, *Pagrus major* (Chen *et al.*, 2003a) and LJES1 from sea perch, *Lateolabrax japonicus* (Chen *et al.*, 2003b). These two lines have been maintained for more than 50 passages *in vitro* and characterized for traits of pluripotency. They have been induced to differentiate into various cell types after treatment with retinoic acid (RA). Holen and Hamre (2003) derived a long-term embryonic stem cell–like culture from the turbot, *Scophtalmus maximus* and these cells expressed Oct4 transcription factor. Two other cell lines, FEC from the flounder (Chen *et al*., 2004) and TEC from turbot, *Scophthalmus maximus* (Chen *et al.*, 2005), have been developed and partially characterized. More recently Chen *et al*. (2007) developed pluripotency and chimera competence of an embryonic stem cell line from the sea perch (*L. japonicus*).

In spite of the feasibility of ES cell line derivation in commercial species, a main obstacle is the production and evaluation of chimeric animals resulting from technical disadvantages when compared with model species, including difficulties in handling and rearing, as well as long generation times (2 to 3 years to reach sexual maturity). In this way only chimeras have been obtained so far in the gilthead seabream and with low efficiency (Bejar *et al*., 2002). Because of the expensive and time-consuming process, the methodology of chimera production must be optimized in model species before application to commercial fish.

Fish embryonic stem cells - applications

There is scope for application of embryonic stem cell technology to commercial fish species to improve productivity by transgenesis. Research efforts on development of transgenic fish with enhanced resistance to pathogens and better growth and breeding performance/colour manipulations in ornamental fishes will be beneficial to the development of aquaulture technologies. ES cells, have the intrinsic ability to self-renew and can be applied to biodiversity rescuing, gene-targeting and germ-line transmission. In fisheries, there is scope for application of induced pluripotent stem cells (iPSCs) which are produced by reprogramming adult somatic cells using pluripotency genes, especially in the case of difficult to breed large sized marine fish species as well as in the case of endangered species. In human medicine, stem cell research offers the possibility of curing fatal and debilitating diseases; in aquaculture, it may enhance fish production and reduce environmental risks. Stem cell lines that could potentially be used to modify the genetic traits of any fish species are being developed in different parts of the world. Fish ES/iPS cell lines have many avenues for fish biology, functional genomics, molecular embryology and conservation of biodiversity.

The piscine embryonic stem (ES) cells have attracted the attention of fish breeders and molecular biologists owing to its possible importance in producing transgenic fish with site-directed integration of foreign gene and in studying gene function in fish. ES cells provide unique tool for cell-mediated gene transfer and targeted gene mutations due to the possibility of *in vitro* selection of desired genotypes. When ES cells colonize germ cells in chimeras, transgenic animals with modified phenotypes are generated and used either for functional genomics studies or for improving productivity in commercial settings. Establishment of ES gene targeting techniques in cultured fish provides a novel approach for genetic improvements; developmental biology and analysis of gene function in fish.

Embryonic stem (ES) cells represent promising cellular vehicle for the production of genetically modified fish. ES cells provide unique tool for cell-mediated gene transfer and targeted gene mutations due to the possibility of *in vitro* selection of desired genotypes. When ES cells contribute to the germ line in chimaeric embryos, transgenic animals may be generated with modified genetic traits. Though the ES cell approach has up to now been limited to mice, there is an increasing interest to develop this technology in both model and commercial fish species, with so far promising results in the medaka (*Oryzias latipes*) and zebrafish (*Danio rerio*). ES cell lines have also potential application for colour manipulations in ornamental fish and also as model systems for therapeutic research in aquaculture.

Taking into consideration, the non-invasive and easy access to fish embryos due to its natural oviparous mode of reproduction as compared to the viviparous mode of mammalian reproduction, fish embryos neither evoke ethical issues nor involve invasive interventions. However, ethical issues involved in using human embryos for deriving ES cells have led to the development of induced pluripotent stem cells (iPSCs). iPSCs are produced by reprogramming somatic cells using pluripotency genes. iPSCs were first developed by Takahashi and Yamanaka (2006) from mouse fibroblasts and later from human somatic cells by several workers (Thompson *et al*., 2007; Okita *et al*., 2008; Woltjen *et al*., 2009). These pluripotent cells can differentiate into any type of cell in the body and proliferate indefinitely in culture. In fisheries, there is scope for application of iPS cell technology especially in the case of difficult to breed large sized marine fish species as well as in the case of endangered species. iPS cell lines developed by reprogramming primary fibroblasts from adult fish tissues could be attempted for deriving germ cells and subsequently for development of surrogate broodstock technology. Surrogate broodstocking could be made use of especially in the case of large aquaculture species or endangered species of fish by transplanting germ cells into small fish species that matures fast, and then use the eggs produced for larval production. This technology has already been attempted to produce eggs of endangered species of trout in salmon (Okutsu *et al*., 2009)

Laboratory fish species, in particular zebrafish and medaka, have been the focus of research towards stem cell cultures. Medaka is the second organism (next mouse) that generated ES cells and the first that gave rise to a spermatogonial stem cell line capable of test-tube sperm production. Most recently, the first haploid stem cells capable of producing whole animals have also been generated from medaka. ES-like cells have also been reported in zebrafish and several marine species. Attempts for germline transmission of ES cell cultures and gene targeting have been reported in zebrafish. Recent years have witnessed the progress in markers and procedures for ES cell characterization. These include the identification of fish homologs/paralogs of mammalian pluripotency genes and parameters for optimal chimera formation. In addition, fish germ cell cultures and transplantation have attracted considerable interest for germline transmission and surrogate production. Haploid ES cell nuclear transfer has proven in medaka the feasibility of semi-cloning as a novel assisted reproductive technology. These pioneer experiments demonstrate the possibility of surrogate production of aquaculture broodstock by germ cell transplantation. This approach might be extended to propagate/restore a population of endangered species in conservation biology.

The derivation of germ cells from fish embryonic stem cells (ESCs) or induced pluripotent stem (iPSCs) cells represents a desirable experimental model and potential strategy for improving reproductive performance of commercially important difficult to breed fish species. Moreover, ES cells may be a method to preserve biodiversity in species for which embryo or gamete cryopreservation is not possible. Recent progress in fish stem cell culture and transplantation will provide valuable systems and tools for basic research and applications in sustainable aquaculture and fish biodiversity conservation

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CHAPTER

42

Marine Molluscan Taxonomy and Biology - An Overview

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Introduction

Molluscs are a phylum of soft-bodied invertebrates which includes Gastropoda (snails, limpets whelks and slugs), Bivalvia (oysters, mussels, clams, scallops, and cockles) and Cephalopoda (squids cuttlefishes, and octopuses). Of these, the gastropods, with large and diverse group (about 80% of all molluscs). The remaining groups such as Monoplacophora (cap-shaped neopilinids), Polyplacophora (chitons), Scaphopoda (tuskshells), Solenogastres (crawling worm-molluscs), and Caudofoveata (shell-less burrowing worm-molluscs) are known to a much lesser extent (Haszprunar and Wanninger, 2012). Brief description about the major groups of molluscs is shown in Table 1.

Molluscs are originally originated in marine water, spread to freshwater and on to the land. Freshwater and landforms are almost equal to the marine forms. Molluscs primarily inhabit in the intertidal and littoral zones of the sea, occasionally descend to a greater depth upto 10,000 m. Molluscs belonging to different taxonomic groups have been exploited for food, pearls, and shells. The estimate number of species of molluscs vary from different parts of the world, however, estimates number of existing species are about more than 1,00000 (Haszprunar and Wanninger, 2012). About 5070 species have been reported from India belonging to 290 families and 784 genera which are recorded from Gulf of Mannar (428 species), Lakshadweep (424 spp.), Gulf of Kutch (350 spp.), Orissa coast (337 spp), West Bengal coast (425 spp.) and Andaman & Nicobar Islands (1434 spp). Nearly 3,370 species of molluscs are recorded from marine habitat (Venkataraman and Wafar, 2005). Among these, gastropods are the most diverse, followed by bivalves, cephalopods, polyplacophores and scaphopods. At present over 1.5 lakh tonnes of cephalopods, over 1 lakh tonnes of bivalves and nearly 20,000 t of gastropods are exploited from Indian waters. The large number of marine gastropods (19 species)

Table 1. Major taxonomic groups of molluscs (Source: Haszprunar and Wanninger, 2012)

Gastropoda	Comprises more than 1,00000 species that inhabit all marine, freshwater and terrestrial habitats and size range from 0.5 mm to 100 cm in body length. All types of feeding habits (filter-feeders, herbivores, predators, ecto- and endoparasites, and detritovores) and all mode of reproduction are found in this group.
Bivalvia	Includes more than 20,000 extant species (1mm to over 150 cm) that live in all kinds of marine and freshwater habitats. They are not only filter feeder, but also include detritivorous and carnivorous bivalves. Some of them also use symbiotic zooxanthellae for nourishment. Most are epibenthic or burrow in soft bottoms, some burrow in limestone, wood (eg. shipworms). Fertilization is mostly external. Trochophore, veliger and glochidia type larvae are known in this group.
Cephalopoda	Comprises only about 1,000 extant species that inhabit exclusively marine and range from 3 cm up to 7m in body length. Some members (Nautiloidea and Ammonitoidea) have external

	shells, while all other (Coleoidea) have internal, reduced / lost shells. All bear 8 - 10 arms (about 80 arms in Nautilus) for capturing prey. Fertilization is external.
Scaphopoda	Includes about 800 marine species of 2mm to 20 cm body length. They burrow in sand or mud and feed chiefly on foraminiferans. Fertilization is external and they have lecithotrophic (trochophore-like) larvae.
Monoplacophora	Comprises less than 30 extant species with a size range from 1-40 mm long. They inhabit from about 200 m down to 7000 m depth. Dorsal surface is protected by a single cup-shaped shell and the mode of feeding is more or less similar to those of chitons.
Polyplacophora	Includes about 1000 extant marine species with range from 3mm to 30 cm body length. Dorsal side is protected by eight serial plates. They are mostly either herbivorous or detritovorous. They have strong rasping tongue for food uptake. Fertilization is external and they have lecithotrophic (trochophore-like) larvae.
Solenogastres	Includes small marine group (280 species) of 1mm to 30 cm body length covered with cuticle with spicules or scales. They live interstitially and feed on cnidarians. The mode of reproduction is through copulation and they have lecithotrophic (modified trochophore or pericalymma - type) larvae.
Caudofoveata	Comprises small marine group (180 species) of 2mm to 15 cm body length covered with cuticle with spicules or scales. They burrow in sand or mud and lose their foot sole entirely. They have lecithotrophic (modified trochophore type) larvae.

Table 2. List of scheduled marine molluscs from India

Endangered list of molluscs	
Class: Gastropoda	
1	*Cassis cornuta* (Linnaeus, 1758)
2	*Charonia tritonis* (Linnaeus, 1758)
3	*Conus milneedwardsi* Jousseaume,1894
4	*Cypraecassis rufa* (Linnaeus, 1758)
5	*Tudicla spirillus* (Linnaeus, 1767)
6	*Staphylaea limacina* (Lamarck, 1810) (= *Cypraea limacina*)
7	*Leporicypraea mappa* (Linnaeus, 1758) (= *Cypraea mappa*)
8	*Talparia talpa* (Linnaeus, 1758) (= *Cypraea talpa*)
9	*Pleuroploca trapezium* (Linnaeus, 1758) (= *Fasciolaria trapezium*)
10	*Harpulina arausiaca* (Lightfoot, 1786)
11	*Dolomena plicata sibbaldi* (G.B. Sowerby II, 1842) (= *Strombus plicatus sibbaldi*)
12	*Ophioglossolambis digitata* (Perry, 1811) (= *Lambis crocea*)
13	*Lambis millepeda* (Linnaeus, 1758)
14	*Lambis scorpius* (Linnaeus, 1758)
15	*Lambis truncata* ([Lightfoot],1786)
16	*Harpago chiragra* (Linnaeus, 1758) (= *Lambis chiragra*)
17	*Harpago arthriticus* (Roding 1798) (= *Lambis chiragra arthritica*)
18	*Rochia nilotica* (Linnaeus,1767) (= *Trochus niloticus*)
19	*Turbo marmoratus* Linnaeus, 1758

Class: Bivalvia	
1	*Hippopus hippopus* (Linnaeus, 1758)
2	*Tridacna maxima* (Roding, 1798)
3	*Tridacna squamosa* Lamarck, 1819
4	*Placuna placenta* (Linnaeus, 1758)
Class:Cephalopoda	
1	*Nautilus pompilius* Linnaeus, 1758

followed by bivalves (4 species) and cephalopod (1 species) has been placed in the endangered list which is a major cause of concern (Table 2). The collection, possession and trading of these scheduled molluscs (Table 2) or their products (live or dead) are prosecuted and will attract a punishment of severe imprisonment upto 7 years along with heavy fine under section 50, 51 of wildlife (Protection) Act 1972.

Commercially exploited molluscs of India

Cephalopods

Three groups of cephalopods viz., squids (order Teuthoidea), cuttlefishes (order Sepiiodea) and octopuses (order Octopodidea), are exploited from Indian seas (Table 3). The main species occurring in commercial catches are *Uroteuthis (Photololigo) duvaucelii* (= *Loligo duvauceli*), *Sepia pharaonis*, *S. aculeata* and *Amphioctopus neglectus* (= *Octopus membranaceous*).

Table 3. Commercially exploited cephalopods from Indian Seas

(Source: Mohamed and Venkatesan, 2017)

Species	Common Name	Distribution
Squids		
Uroteuthis (P.) duvaucelii	Indian squid	All along Indian coast
Loliolus (N) uyii	Little squid	Chennai & Visakhapatnam
U (P) edulis	Swordtip squid	SW coast
U (P) singhalensis	Long barrel squid	SW & SE coast
Loliolus (L) hardwickei	Little Indian squid	All along Indian coast
Sepioteuthis lessoniana	Palk Bay squid	Palk Bay & Gulf of Mannar
Sthenoteuthis oualaniensis	Purple-back Flying squid	Oceanic Indian EEZ
Thysanoteuthis rhombus	Diamond squid	Oceanic Indian EEZ
Cuttlefishes		
Sepia pharaonis	Pharaoh cuttlefish	All along Indian coast
S. aculeata	Needle cuttlefish	All along Indian coast
S. elliptica	Golden cuttlefish	Veraval & Kochi
S. prashadi	Hooded cuttlefish	SW & SE coast
S. brevimana	Shortclub cuttlefish	Chennai & Visakhapatnam
Sepiella inermis	Spineless cuttlefish	All along Indian coast

Octopuses		
Amphioctopus neglectus	Webfoot octopus	SW & SE coast and islands
A. marginatus	Veined octopus	SW & SE coast and islands
A. aegina	Marbled Octopus	SW & SE coast and islands
O. lobensis	Lobed octopus	SW & SE coast and islands
O. vulgaris	Common octopus	SW & SE coast and islands
Cistopus indicus	Old woman octopus	SW & SE coast and islands

Bivalves

Various groups of bivalves such as clams, oysters, mussels, and windowpane oysters are exploited along the Indian coast for food and shells (Table 4).

Table 4. Commercial important bivalves of India

Resource	Common name
Clams and cockles	
Villorita cyprinoides	Black clam
Paphia malabarica, Paphia sp	Short neck clam, textile clam
Meretrix casta, Meretrix meretrix	Yellow clam
Mercia opima	Baby clam
Mesodesma glabaratum	
Sunetta scripta	Marine clam
Donax sp	Surf clam
Geloina bengalensis	Big black clam
Tegillarca granosa (= Anadara granosa)	Cockle
Placuna placenta	Window pane oyster
Tridacna sp, Hippopus hippopus	Giant clam
Mussel	
Perna viridis	Green mussel
Perna indica	Brown mussel
Pearl oyster	
Pinctada fucata	Indian pearl oyster
Pinctada margaritifera	Blacklip pearl oyster
Edible oyster	
Crassostrea madrasensis	Indian backwater oyster
Saccostrea cucullata	Rock oyster

Molluscan Fisheries in India

Cephalopods are the most important group of molluscs with estimated all India production of about 2, 61,663 tonnes in 2017 which was 11.6 % more compared to the previous year. They are landed either as by-catch or as a targeted fishery. Targeted fishery is mostly carried out in mechanized trawlers operating upto 200 m depth, and beyond in some areas.

Bivalve fishery is the next in importance and fishing is practiced in limited extent mostly at a subsistence level in various estuaries and coastal seas. Clams and cockles contribute 73.8%, followed by oysters (12.5%), mussels (7.5%) and windowpane oysters (6.2%) (Mohamed and Venkatesan, 2017). The annual average clam production is about 57,000 t, oysters about 18,800 t, and marine mussels about 14,900 t (Mohamed and Venkatesan, 2017). At present, there was no fishery for marine pearl oysters, but it was the major fisheries before 1962 in the Gulf of Mannar area. Scallops occur in certain area in stray numbers and do not contribute in fishery, whereas the windowpane oyster formed considerable fishery till a few year back (Mohamed and Venkatesan, 2017).

Gastropods in India are exploited for both as food and as curios. Among gastropods, the sacred chank is most important with annual production of over 1,000 t till a few years back (Mohamed and Venkatesan, 2017). The fishing of top shell *viz., Rochia nilotica* and *Turbo marmoratus* has been banned as they have been declared as endangered. One species of Abalone *viz., Haliotis varia* occur in stray numbers and are not fished. Mining for subsoil shell deposits was carried out from time immemorial especially in the Ashtamudi and Pulicat Lakes for industrial purposes.

Mollusc biology

Molluscs are extremely large group and diverse in all phases of life. They occur in all marine habitats of the world including deep-sea hydrothermal vents, freshwater environments upto 40° C, land (gastropod alone) and permanent ice (Haszprunar and Wanninger, 2012). They range in size from 0.4 mm (omalogyrid gastropods) to more than 15 m (*Architeuthis* squids) (Haszprunar and Wanninger, 2012). Their longevity can range from a few months to up to more than 150 years (Deep sea giant bivalves) (Haszprunar and Wanninger, 2012). They mostly crawl or glide through cilia or muscle waves with mucous (Haszprunar and Wanninger, 2012). Some animals can permanently cement to the substrate, such as giant clam and edible oyster while some can attach to the substrate through byssus thread such as mussels. Modes of feeding are also diverse including filterfeeders , omnivores, predators, grazers, detritovores , ecto- and endoparasites, and various kind of symbioses with bacteria, plankton (Zooxanthellae), and algae.

The body of theoretical molluscs comprises five fundamental parts – the foot, the head, the visceral mass, the mantle and the shell. The alimentary tract or system of theoretical molluscs consists of ingestion, digestion, absorbtion and assimilation of food. The system starts with mouth which leads to the buccal cavity having pair of jaws in each side. Pharynx, located at the anterior of the buccal cavity, is occupied by the *odontophore* which supports the tongue like structure called *radula*. Ducts from one or two pairs of salivary glands are present at the anterior of pharynx which in some species (*Conus* sp) are modified into organs to secret venom used to paralyze or kill the prey. The tract goes on with the esophagus and then enlarges in a stomach where the food has been partially digested as threads of particles linked together by mucus. Food is mostly digested in the ducts of two large digestive glands by tiny cilia (whiplike structure). These digestive glands occupy almost all the space within the visceral mass. Digestion of molluscs takes place both extracellularly and intracellularly. Extracellular digestion occurs especially in the stomach while, intracellular digestion takes place especially in the hepatopancreas. These organs (stomach / hepatopancreas) do the dual functions – secretion of digestive enzymes and absorption of food particles. The structure of posterior portion of the stomach is conical in many molluscs and a translucent rod shape in bivalves. This structure is known as *crystalline style* which secrets enzymes to digest certain carbohydrates. After the stomach comes the intestine which opens at the anus into the pallial cavity.

Circulatory system in molluscs is open except cephalopods. Heart, made up of two dorsal auricles/atria and a single ventricle, gets only oxygenated blood from gills and send it to different regions of the body through posterior aorta. Blood/hemolymph transport through blood vessels directly to the openings or spaces between the organs. Respiratory pigments in molluscs are of two main types *viz.,* red hemoglobin and blue, copper containing hemocyanin.

Excretory system removes the waste materials that are formed from the breakdown of assimilated food chiefly nitrogenous waste such as ammonia and urea. This function is carried out by one or more kidneys which are diverse in the various groups of molluscs. In primitive group, these organs are linked to the pericardial cavity and at least one of the excretory passages is modified to form a gonoduct for transfer of gametes. Excretory system opens into the pallial chamber. Pallial chamber is also an important structure which mediates between the animal and its external environment.

Respiratory system in molluscs is generally formed by the pair of gills in the pallial chamber. However, most of the gastropods have single gill. Gills are the site of gas exchange and look like a feather, with a central axis. Gills are of different forms in different group of the molluscs depending on their environment and feeding habits. Land snails do not possess gills instead they have primitive form of lung.

Molluscs show various mode of reproduction. Most of them are either gonochoristic or hermaphroditic. Percentage of gonochoristic and hermaphroditic species are more or less equal (Haszprunar and Wanninger, 2012). Few of them occasionally show parthenogenesis. Majority of the molluscs, especially gastropods and cephalopods transfer sperm by means of copulatory organs, whereas, many species, especially gastropods, scaphopods and chitons shed their gametes liberally into the water. Their egg sizes range from about 80 µm (many bivalves and gastropods) to 2 cm (*Nautilus* spp) (Haszprunar and Wanninger, 2012).

Larvae of them are either intracapsular or direct development into miniature form or planktotrophic or lecithotrophic. Larvae may look different from adult form. Typical molluscan larvae are veligers which are usually more or less modified form of Trochophore larvae. Example of special type of larvae is glochidium of freshwater unionoids which is well known as parasite on fish gills.

Biology of commercially important cephalopods

All cephalopods are active predators that feed on live prey, mainly fishes and crustaceans. Fish always occurs in the diet of squid *U.(P.) duvaucelii* of all sizes (Mohamed and Joseph, 2005). The fondness of crustacean diet diminishes with increase in size and there is indication of cannibalism above 80 mm DML (Oommen, 1977). Cephalopods are one of the major preys for a variety of marine fishes including tunas, billfishes, cetaceans, and whales (Silas, 1985). Many researchers have observed the high proportion of empty stomachs in samples and fatigue in feeding during spawning (Oommen, 1977).

The characteristic of length weight relationship of Indian cephalopods has been reported to be hypoallometric with the 'b' value is lower than 3 (Meiyappan *et al.,* 1993). This relationship is also significantly different for males and females (Mohamed, 1996).

Cephalopods along the Indian coast are reported to spawn almost throughout the year. The earlier work on the reproductive biology of the Palk Bay squid *Sepioteuthis lessoniana* has been carried out by Rao (1954). Later on, the maturity of three species of squids and six species of cuttlefishes has been reported by Silas *et al.* (1985ab). Size at first maturity (Lm) and peak spawning seasons of some of the studied species is given in Table 5. Maturity stages for biological studies of squids and cuttlefishes have been standardized (Silas, 1985) and described as four-point (Immature, Maturing, Mature, and Spent) maturity scale. This maturity scale has been used by all workers on Indian cephalopods.

Mature and partially spawned individuals of *U. (P) duvaucelii* are found throughout the year along both the coasts, but along the west coast, peak spawning has been observed during post monsoon i.e. Sep-Nov. (Silas *et al.*, 1985a; Mohamed, 1993). This species forms large congregation during this season and becomes vulnerable to the purse seine fleet operating along Karnataka coast (Mohamed, 1993) and also to cast netters along coastal water of Alleppey (Meiyappan and Srinath, 1989). This squids congregate for spawning in near shore waters after which the female migrate to the shallow subtidal regions with hard substratum for laying the fertilized eggs (Mohamed, 1993). Fertilized eggs from the subtidal regions of Karwar seas have been collected for rearing (Asokan and Kakati, 1991). Based on sex ratio (M 80:F20) of such squid schools, it would be easy to conclude that female was semelparous. However the evidence such as relatively low GSI levels and the occurrence of mature females over a wide range of size classes, suggests that this species is multiple spawner and not a semelparous species (Mohamed, 1993). Similar studies in other commercial cephalopods are not availableTable 5.Biology of the commercially important cephalopods (Source: Silas *et al*, 1985ab; Abdussamad et al., 2004; Abdussamad & Somayajulu, 2004; John Chembian, 2013, Sajikumar (unpublished))

Table 5.Biology of the commercially important cephalopods (Source: Silas et al, 1985ab; Abdussamad et al., 2004; Abdussamad & Somayajulu, 2004; John Chembian, 2013, Sajikumar (unpublished))

Species	Lm (mm)	Spawning period	Peak Spawning	Region/coast
U.(P) duvaucelii	76 (M);86 (F)	Throughout the year	Feb & Jun - Sep (Chennai) Jan, Jul & Sep (Waltair)	East coast
	113 (M);118 (F)		Feb-Mar, May-Jul, Sep-Oct (Kochi)	West coast
S. lessoniana	102 (M);98 (F)	Jan-Jun		East coast
U.(P) singhalensis	126(M);135(F)	Jan-Mar; Oct&Dec		West coast
S. aculeata	102-118 (F)	Throughout the year (Mandapam) Mar-Jun &Nov (Portonovo) Feb-Dec (Chennai) Nov-Jul (Waltair) Aug-Mar(Kakinada)	Aug-Sep(Mandapam) Feb, Jun-Aug &Oct-Dec(Chennai) Apr, Jul, & Nov-Dec (Waltair) Nov-Dec (Kakinada)	East coast
	130-132(F)	Nov-Dec (Kochi) May, Aug, Sep,& Dec (Mumbai)		West coast
S.pharaonis	120 (F)(Waltair)	Jan-Feb, Apr & Sep-Dec(Waltair) Aug-Mar(Kakinada)	Sep-Dec, Feb, & Apr-Jun Nov-Dec (Kakinada)	East coast
	138 (F) (Chennai) 160 (F) (Vizhinjam) 157(F) (Kochi)	Throughout the year (Chennai) Jan, Mar-Apr, Sep-Oct, Dec (Vizhinjam) Feb, Apr, Jun, Oct & Dec (Kochi)	Oct-Dec, Mar-Apr	West coast
S. brevimana	63(F) (Chennai) 59(F) (Waltair)	Jan-Feb & Jul-Dec		East coast
S. elliptica	93-96 (M&F)	Aug-April & Jun (Kochi)		West coast
S. inermis	52(Waltair)	Apr,Jun-Sep & Nov-Dec (Waltair)		East coast
	61 (Chennai)	Feb-Mar, & Jul-Dec (Chennai)	Sep, Dec & Mar (Chennai)	
	50 (Portonovo)	Mar-Oct (Portonovo) Apr-Nov (Kakinada)		
	83(Kochi)	Apr, Sep-Dec (Kochi)	Sep & Oct (Kochi)	West coast
S. oualaniensis	128 (M);170 (F)	Throughout the year	Oct-Dec & Mar-May	West coast
T. rhombus		Oct -Feb		West coast

Fecundity studies on Indian cephalopods are few. Individuals of *U.(P) duvaucelii* produced 5300 eggs on an average (Rao, 1988) while, fecundity estimate of *S. inermis* (69 - 71 mm DML) was ranged between 470 - 850 eggs (Unnithan, 1982). There was good correlation between length, ovary weight, and fecundity in *U.(P) duvaucelii*. In *S. lessoniana* (120 - 196 mm DML), total number of ripe eggs was from 180 to 1054 egg (average 497 eggs) (Venkatesan and Rajagopal, 2013). Fecundity, ovary weight and nidamental gland weight showed strong correlation, while fecundity, DML, and body weight showed relatively weak correlation.

Biology of commercially important bivalves

The biology of commercially important species of bivalves from India is given in Table 6. Physical factors such as temperature and salinity are the important factors for influencing the reproductive cycles and spawning in bivalves (Sastry, 1979). In addition to temperature, food

Table 4. The biological details of the commercially important bivalves (Source: Kripa and Appukuttan, 2003)

Species	L_m	Spawning period	L_{max}	Length (mm) in I yr	II yr	III yr	Distribution
V.cyprinoides	20 - 25	May-June & Nov	52	30	41	-	West coast
P. malabarica	20	Sep-Feb	55	43.1	-	-	West coast
P. viridis	15.5-28	Dec-Jan Jul-Nov		91.5 96	117 117	129 129	East coast West coast
C. madrasensis	12-14(M) 24-26(F)	Nov-Feb Jul-Sep Feb-Apr	128	86 70-80	112 90-110	 120-130	East coast West coast
M. casta	11-17.	Throughout the year	55	42.6			East &West coast
M. meretrix	21-26	May-June Feb - Sep	91	47	61.5		East coast
M. opima	11-20.	Dec May-Aug	53.8	30 22	43.5 31	 43	East coast West coast
T. granosa	20-24	Throughout the year	73.4	41.1	55.3	66.3	East coast

supply and latitudinal distribution effects the reproductive cycle of bivalves (Newell *et al.*, 1982). The number of spawning events and duration of spawning period can also differ greatly with respect to species, geographic area and environmental conditions (Gosling, 2003). In general, an environment play an important role to influence the growth, reproduction and recruitment of bivalves and same species shows different growth rates and spawning periods in different areas (Kripa and Appukuttan, 2003). They found that the combination of different hydrographic parameters like salinity, availability of settlement substrate and current pattern are responsible for controlling the spat fall, population growth, zonation and species dominance. Although, most of bivalves are gonochoristic, in certain bivalves like oysters hermaphroditism has been observed.

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